2.2010-105
University of Alberta Library
0 1620 3415566 1

Chemistry 20

Learn EveryWare

we educate

Module 5
ACIDS AND BASES

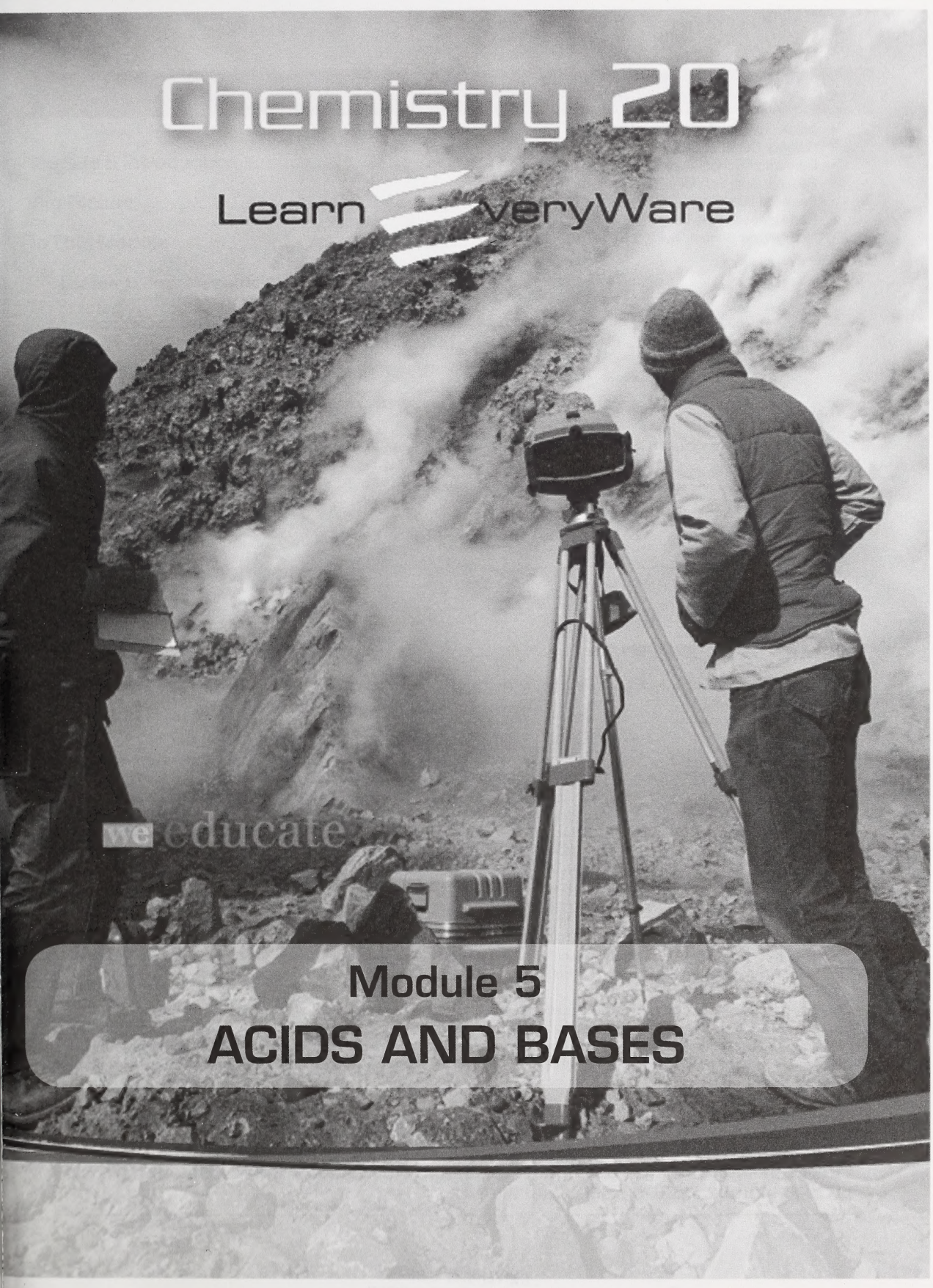
Red Deer Catholic Regional Schools
PEMBINA HILLS REGIONAL SCHOOL DIVISION NO. 7
EDMONTON PUBLIC SCHOOLS
BLACK GOLD REGIONAL SCHOOLS
PEACE WAPITI SCHOOL DIVISION NO. 76
Calgary Board of Education
Alberta Education

Digitized by the Internet Archive
in 2017 with funding from
University of Alberta Libraries

https://archive.org/details/chemistry2005albe

Chemistry 20

Learn EveryWare



Module 5

ACIDS AND BASES

Chemistry 20 was created by Alberta Education in partnership with the following educational jurisdictions under the terms of the *BCP Collaborative Course Development Project*:

- Black Gold Regional Schools
- Calgary Board of Education
- Edmonton School District No. 7
- Peace Wapiti School Division No. 76
- Pembina Hills Regional Division No. 7
- Red Deer Catholic Regional Division
- Rocky View School Division No. 41

Chemistry 20
Module 5: Acids and Bases
Student Module Booklet
ISBN 978-0-7741-3040-0

Cover Art: © Photodisc/Getty Images

This document is intended for	
Students	✓
Teachers	✓
Administrators	
Home Instructors	
General Public	
Other	

You may find the following Internet sites useful:

- Alberta Education, **http://www.education.gov.ab.ca**
- Learning Resources Centre, **http://www.lrc.education.gov.ab.ca**
- Tools4Teachers, **http://www.tools4teachers.ca**

Exploring the electronic information superhighway can be educational and entertaining. However, be aware that these computer networks are not censored. Students may unintentionally or purposely find articles on the Internet that may be offensive or inappropriate. As well, the sources of information are not always cited and the content may not be accurate. Therefore, students may wish to confirm facts with a second source.

Copyright © 2008, Alberta Education. This resource is owned by the Crown in Right of Alberta, as represented by the Minister of Education, Alberta Education, 10155 – 102 Street, Edmonton, Alberta, Canada T5J 4L5. All rights reserved.

No part of this courseware may be reproduced in any form, including photocopying (unless otherwise indicated), without the written permission of Alberta Education. This courseware was developed by or for Alberta Education. Third-party content has been identified by a © symbol and/or a credit to the source. Every effort has been made to acknowledge the original source and to comply with Canadian copyright law. If cases are identified where this effort has been unsuccessful, please notify Alberta Education so corrective action can be taken.

This courseware may contain one or more audio and/or multimedia components. Please review the Terms of Use Agreement on each for additional copyright information.

THIS COURSEWARE IS NOT SUBJECT TO THE TERMS OF A LICENCE FROM A COLLECTIVE OR LICENSING BODY, SUCH AS ACCESS COPYRIGHT.

UNIVERSITY LIBRARY
UNIVERSITY OF ALBERTA

Contents

Module 5 Introduction 2

Big Picture 3

In This Module 3

Lesson 1: Properties of Acids and Bases 5

Lesson 2: Calculating pH and pOH 14

Lesson 3: Strength of Acids and Bases 21

Lesson 4: Multi-step pH and pOH Calculations 29

Lesson 5: Indicators 43

Module Summary 50

Module Assessment 50

Unit C Conclusion 51

Unit C Assessment 52

Module Glossary 55

Self-Check Answers 56

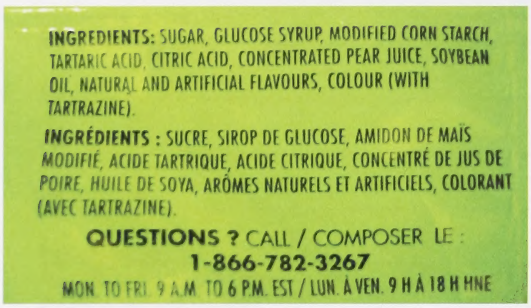
Chemistry 20

Unit C Matter as Solutions, Acids, and Bases

Module 5—Acids and Bases

Module Introduction

Recall from previous science courses that acids taste sour. The sour "kick" of many foods people eat is due to acids—often listed as ingredients. You may also recall your teacher cautioning you in the laboratory that acids can damage your skin. Knowing this, have you ever wondered why some acids can be used in foods? Does the concentration of an acid influence its properties? Do other factors influence the observable characteristics of acids? How can two acidic solutions with equal solute concentrations have different pH values?



In this module you will learn the answers to these questions and explore several aspects of acid-base chemistry.

In Lesson 2, there are theories, like Arrhenius's theory, that attempt to explain and predict the behaviour of acidic and basic substances when they are dissolved in an aqueous solution. However, you may have found situations where this theory was not adequate when explaining and predicting your observations of the behaviour of an acid or base. In this module you will learn why and in what way the Arrhenius theory had to be modified to overcome these limitations.

- Scientific theories are human inventions used to explain events that occur in nature and predict future results. While learning acid-base chemistry, you will pay more attention to different theories. What are the limitations of the different theories you will use?

- How do significant digits communicate the appropriate information about acidic and basic solutions?

Big Picture

Opening the door of a refrigerator not only reveals many food options, but it also reveals a world of chemistry. In Module 4 you encountered some refrigerator chemistry with the study of gas solubility in soda pop and salt solubility in pickle juice. There is much more chemistry happening in your fridge than just solubility!

© Image courtesy of Canstockphoto.com

Foods, in particular, can be studied in the context of acid-base chemistry, since nearly every item in your fridge contains acidic or basic molecules. An understanding of acid-base chemistry is an essential component of food science.

In this module you will study the experimental and theoretical foundations of acid-base chemistry and learn about how some common food items can be used to demonstrate these principles.

In This Module

Lesson 1: Properties of Acids and Bases

Acids and bases had been used for centuries long before any theoretical understanding for their behaviour. In this lesson you will briefly review concepts related to acids and bases introduced in Science 10. Once you complete this review, you will learn about Arrhenius's theory, its limitations in explaining and predicting the behaviour of acids and bases, and about a new particle called the hydronium ion.

- What are the empirical properties of acids and bases?
- How are acids and bases named?
- Why is the original Arrhenius theory considered to be an incomplete explanation of the behaviour of acids and bases?

Lesson 2: Calculating pH and pOH

The concentration of acidic or basic particles within a chemical system can be expressed using a number other than molar concentration. What mathematical formulas are required to calculate these values? In this lesson you will learn how to associate pH and pOH with the acidity or basicity of a solution and gain an understanding of the relative concentrations of hydronium and hydroxide ions within a solution.

- How do you calculate pH, $[H3O^{+}(aq)]$, pOH, and $[OH^{-}(aq)]$?

Lesson 3: Strength of Acids and Bases

Equal concentrations of ethanoic acid, commonly called vinegar, and hydrochloric acid will not have the same pH. Why? How do weak acids and bases differ from strong acids and bases? How can any differences be explained using the theories that have been introduced throughout this unit?

- How are the empirical properties of weak acids and bases different from those of strong acids and bases?
- What are polyprotic acids and bases?

Lesson 4: Multi-step pH and pOH Calculations

In this lesson you will apply the formulas introduced in Lesson 3 to help you address a variety of practical applications, including

- preparing a solution with a specific pH
- predicting the pH of a solution using the mass of solute
- predicting the pH of a solution produced by the dilution of another solution
- How are ionization and dissociation accounted for when calculating concentration of acidic and basic particles within a solution?
- How can a solution's pH be predicted using mass of solute and solution volume?
- Why is the pH of a diluted solution able to be predicted?

Lesson 5: Indicators

pH can be estimated using acid-base indicators. Indicators are molecules that have distinct colours at various pH values. In this lesson you will learn how to use indicator colour to estimate the pH of a solution. You will also complete a virtual lab that demonstrates how to use indicators.

- What are acid-base indicators?
- How are acid-base indicators used to estimate the pH of a solution?

Module Assessment

The assessment in this module consists of the following:

- Module 5: Lesson 1 Assignment
- Module 5: Lesson 3 Assignment
- Module 5: Lesson 4 Assignment
- Module 5: Lesson 5 Assignment

Lesson 1—Properties of Acids and Bases

Get Focused

It's a long weekend in the summer. You and your family decide to enjoy the weather by going on a camping trip.

Upon returning home, you find that your refrigerator has malfunctioned and most of the food inside has spoiled. There is a strong, rancid odour; and it persists even after all of the food has been removed.

After a brief Internet search, you come across a website that recommends using baking soda to remove the odour from your fridge. So, you and your family try this method. A few hours after you leave an open box of baking soda in the fridge, the intensity of the odour is noticeably less.

Why can baking soda reduce the intensity of an odour in a refrigerator? How are principles of acid-base reactions demonstrated in this and in many other chemical reactions?

Essential Questions

- What are the empirical properties of acids and bases?
- How are acids and bases named?
- Why is Arrhenius's original theory considered to be an incomplete explanation of the behaviour of acids and bases?

Module 5: Lesson 1 Assignment

In this lesson you will complete the Lesson 1 Assignment in the Module 5 Assignment Booklet. Later in the lesson you will receive more information about how to complete this assignment and when to submit it to your teacher.

The other questions in this lesson are not marked by the teacher; however, you should still answer these questions. The Self-Check and Try This questions are placed in this lesson to help you review important information and build key concepts that may be applied in future lessons.

In this lesson you will also consider how you would test the cleaning powers of some common acids and bases.

Explore

Try This

An Acid-Base Reaction

What do you understand about acids and bases? In previous science courses you may have investigated their properties, but how do they behave when they are combined? In this activity you will examine the reaction of baking soda (sodium hydrogen carbonate) with vinegar (an aqueous solution of ethanoic acid). Follow these steps:

Step 1: Write the chemical formulas, including their states, for solid sodium hydrogen carbonate and aqueous ethanoic acid.

Step 2: Place 50 mL of vinegar into a 100-mL beaker or drinking glass.

Step 3: Add 5 mL (1 teaspoon) of baking soda to the beaker containing the vinegar.

Step 4: Observe any changes that occur.

TR 1. A group of Chemistry 20 students suggests that the balanced chemical equation for the reaction between baking soda and vinegar is

$$NaHCO3(s) + CH3COOH(aq) \rightarrow NaCH3COO(aq) + CO2(g) + H2O(l)$$

Use your observations to support or argue against the suggested equation. Identify any additional tests you might want to perform to support your answer.

Check your work with the answer in the appendix.

Discuss

The reaction you observed in the Try This activity above is identical to the reaction you used to simulate the eruption of a volcano when you completed Module 1, Lesson 5. Chemical reactions often form the basis of many science projects and toys.

Use the Internet, or other sources of information, to find a project or toy that requires the reaction between baking soda and vinegar.

Prepare a brief summary of the project or activity that explains why this chemical reaction is involved. Include a list of the sources you used to prepare your summary.

Post your summary to the class discussion area. Read the summaries from a minimum of three other students and identify similarities and differences in the way the reaction is used.

Copy your posting into the appropriate section in the Lesson 1 Assignment. Complete other parts of the table. After you have completed Part 1 of the Lesson 1 Assignment, save your work to your course folder. You will receive information about how to complete the other part of the assignment later in this lesson.

Read

Acids and Bases—Review of Basic Concepts

Acids and bases can be defined using empirical and theoretical definitions.

Read "Acids and Bases" on pages 198 and 199 in your textbook to review these definitions.

Read the information in the table below. What kind of information is provided here, empirical or theoretical information?

	Acids	Bases
Conductivity	conductive	conductive
Litmus	turns blue litmus red	turns red litmus blue
Taste	sour	bitter
Feel	similar to water	slippery
pH	pH less than 7	pH greater than 7
Reaction with Mg(s), Zn(s), or Fe(s)	produces hydrogen gas	does not produce hydrogen gas
Reaction with other substances	neutralized by bases	neutralized by acids

Empirical definitions, like those in the table, describe acids and bases in terms of their behaviour during chemical tests. Empirical definitions only provide one type of knowledge about substances and may not provide information as to why such behaviour is observed.

Turn to pages 248 to 253 of your textbook and read "6.4 Explaining Acids and Bases" to learn more about the theories about acids and bases you will use in this module. As you read this section, make summary notes on the following:

- the difference between dissociation and ionization
- the particle identified as providing a solution with its acidic properties by the different theories discussed
- the particle identified as providing a solution with its basic properties by the different theories discussed
- the particles involved during a neutralization reaction
- how a neutralization reaction can result in "neutral" products

You may wish to include, as often as possible, examples of chemical reactions that are helpful for your summaries and explanations.

You may also wish to review the rules regarding the naming and writing formulas for acids and bases. These rules appear on pages 34 to 36 in your textbook.

Self-Check

SC 1. Earlier, you examined a table listing the empirical properties of acids and bases. Discuss any benefits, limitations, or concerns with using each of the tests listed in the table to categorize a solution as being acidic, basic, or neutral.

SC 2. Write a balanced equation for the change associated when each of the following substances is dissolved in water. Indicate which changes involve dissociation and which involve ionization.

a. $HF(g) \rightarrow$

b. $Ba(OH)2(s) \rightarrow$

c. $HNO3(aq) \rightarrow$

SC 3. Complete the following table.

Common Name	Systematic IUPAC Name	Formula
	aqueous hydrogen borate	$H3BO3(aq)$
benzoic acid	benzoic acid	
barium hydroxide	barium hydroxide	
	aqueous hydrogen phosphate	$H3PO4(aq)$
hydrosulfuric acid	aqueous hydrogen sulfide	
	aqueous hydrogen chlorite	$HClO2(aq)$
hydroiodic acid	aqueous hydrogen iodide	
carbonic acid	aqueous hydrogen carbonate	
	aqueous hydrogen nitrite	$HNO2(aq)$
	aqueous hydrogen fluoride	$HF(aq)$
acetic acid		
	aqueous hydrogen chromate	$H2CrO4(aq)$
sulfurous acid	aqueous hydrogen sulfite	
		$NaHCO3(aq)$

SC 4. Complete "Practice" questions 1 and 2 on page 251 of your textbook.

Check your work with the answer in the appendix.

Module 5: Lesson 1 Assignment

The following lab will be used to complete part of your Lesson 1 Assignment.

Lab: Testing Arrhenius's Acid-Base Definitions

Read the description for this lab on page 260 of your textbook.

Purpose

You will test Arrhenius's definitions of an acid and a base.

Pre-lab Questions

1. Identify the two ions of interest in this investigation.

2. Describe how the theoretical concepts of dissociation and ionization are important to the ability to classify solutions as acidic, basic, or neutral based on the information you will collect during the laboratory.

Check your work with the answer in the appendix.

Procedure

Step 1: Prepare an experimental design that includes relevant diagnostic tests that could be used to differentiate solutions and classify them as acidic, basic, or neutral. Make sure your design identifies relevant variables and controls.

Step 2: Construct a suitable data table to record and present your observations as determined by your experimental design.

Step 3: Have your experimental design checked by your teacher. Follow instructions provided by your teacher for submitting this component of your work.

Step 4: If you have access to a laboratory and apparatus, perform your experiment and collect all the necessary data.

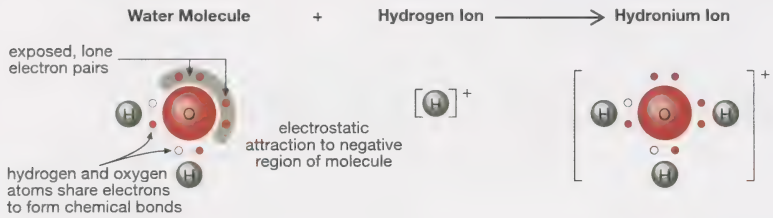
If you do not have access to a laboratory, view the "Testing Aqueous Solutions" slide show and the "Testing Aqueous Solutions: Controls" slide show. Both can be found on your Chemistry 20 Multimedia DVD.

Analysis

Complete the Analysis questions in Part 2 of the Lesson 1 Assignment.

Read

The Hydronium Ion



You may recall that the position of lone pairs of electrons around the surface of a water molecule contributes to its polarity. The tendency of these lone pairs is to attract positive charges. Free hydrogen ions, which have a positive charge, are naturally drawn by electrostatic forces toward water molecules, resulting in the formation of **hydronium ions**.

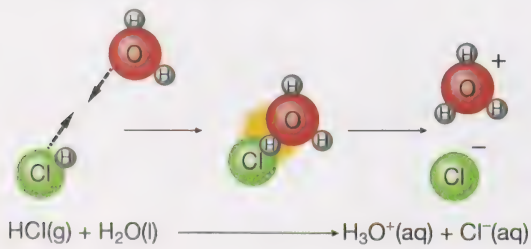
hydronium ion: a hydrated hydrogen ion (proton), $H_3O^+(aq)$; the entity responsible for the acidic properties in an aqueous solution

Examine the structure of the hydronium ion shown in the diagram. Note that all of the hydrogen atoms are covalently bonded to the central oxygen atom. The presence of the lone pair results in a trigonal pyramidal structure for the hydronium ion.

A combination of theoretical and experimental data supports the notion of the hydronium ion as the acidic particle.

- Arrhenius's theory was unable to explain the mechanism by which an acid "falls apart" (ionizes) to yield the hydrogen ion. The ionization of acids can be explained as a result of collisions between solutes and water molecules, in which a hydrogen ion is transferred to the water molecule, bonding to one of the lone pairs of electrons.

Formation of Hydronium Ions



- The observed acidity of substances like $NaHSO_4(s)$ can be explained. A reaction between water and dissociated ions can result in the formation of hydronium ions as is summarized in the two reaction equations:

Dissociation of Solute in Water

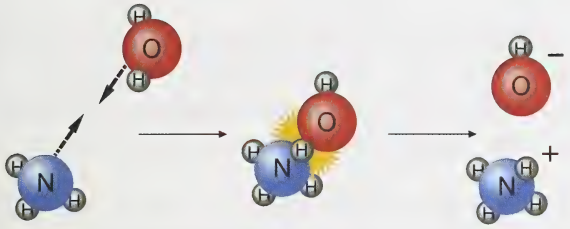
$NaHSO4(s) \rightarrow Na^{+}(aq) + HSO4^{-}(aq)$

Reaction with Water to Form Hydronium Ion

$HSO4^{-}(aq) + H2O(l) \rightarrow H3O^{+}(aq) + SO4^{2-}(aq)$

- The observed basicity of ammonia, NH3(aq), can be explained. Ammonia does not possess any hydroxide ions. So how does it form a base? The answer is that ammonia can react with water to produce a hydroxide ion.

Reaction of Ammonia



$NH_3(aq) + H_2O(l) \longrightarrow OH^{-}(aq) + NH_4^{+}(aq)$

Self-Check

Comparing Theories

SC 5. Prepare a table that lists the acidic and basic particles associated with Arrhenius's theory and its more recent revision. Identify the mechanisms by which these particles are formed for each theory.

Test your knowledge of the material covered in this lesson by completing the following questions.

SC 6. State the similarities and differences between a hydrogen ion and a hydronium ion.

SC 7. Write a balanced chemical equation for each situation stated.

a. HNO3(aq) reacts with water to form an acidic solution.
b. HBr(aq) reacts with water to form an acidic solution.
c. Na2HPO4(s) reacts with water to form an acidic solution.
d. Na2HPO4(s) reacts with water to form a basic solution.
e. Ca(OH)2(s) dissociates to form a basic solution.
f. NaCN(s) reacts with water to form a basic solution.

SC 8. Baking soda (sodium hydrogen carbonate) produces a basic solution when dissolved in water. Explain this result using one of the theories you covered in this lesson.

SC 9. Using the modified Arrhenius theory, write the steps in the neutralization reaction between nitrous acid and aqueous sodium hydroxide.

Check your work with the answer in the appendix.

Module 5: Lesson 1 Assignment

Complete the questions in Part 3 of your Lesson 1 Assignment. Check with your teacher about whether you should submit your assignment now or wait until all of the Module 5 assignments have been completed.

Reflect and Connect

Many of the foul odours from spoiled foods are due to acidic compounds. For example, butyric acid (butanoic acid) is present in rancid butter. Butyric acid can be detected by humans at concentrations as small as 10 ppm.

How does baking soda remove this odour? In the Try This: An Acid-Base Reaction activity at the beginning of this lesson, you mixed baking soda with vinegar. It was very obvious that a chemical reaction was occurring based on the observed foaming and bubbling. When acidic compounds are present in a refrigerator containing an open box of baking soda, the sodium carbonate reacts with the acid and moisture contained within the air inside, neutralizing the odour.

Is baking soda the best choice for removing odours in a refrigerator? Use the Internet or your library to research other substances that have the ability to neutralize odours. Select one of these substances, and write an experimental design that could be performed to compare the effectiveness of this substance with baking soda as a deodorizer. Perform the experiment, and write a paragraph detailing the results.

Include your experimental design, all the data collected, and your results in your course folder and submit them to your teacher for assessment if you are instructed to do so.

Reflect on the Big Picture

Baking soda and vinegar are two products that have potent cleansing properties. You can use the Internet to find recipes for many cleaners that use non-toxic materials found in your kitchen. Use the combination of search terms *cleaners*, *non-toxic*, and *marketplace* to locate recipes for "green cleaners."

Select two recipes for cleaning solutions that you wish to investigate; then complete the following tasks:

- Shoot a video or create a slide show or illustrations of you making the solutions. Indicate what type of cleaner you are making, the ingredients needed, and the steps required to properly mix them together.

- Shoot a video or create a slide show or illustrations of you using each cleaner for its intended purpose. Evaluate the effectiveness of your cleaner against commercial products that do the same job.

Save a copy of the record of your work to your course folder. Make sure that your finished work includes evidence of your experimental design, all the data collected, and your results. Submit to your teacher for assessment if you are instructed to do so.

© matka wariatka/shutterstock

Lesson Summary

In this lesson you explored the following essential questions:

- What are the empirical properties of acids and bases?
- How are acids and bases named?
- Why is Arrhenius's original theory considered to be an incomplete explanation of the behaviour of acids and bases?

Empirical properties can be used to distinguish acids and bases from neutral substances. Taste, feel, pH, reactivity, and conductivity are all useful diagnostic tests for this purpose.

While acids and bases can be used in applications without a theoretical understanding of their behaviour, chemists require a systematic way of dealing with this large class of substances. Naming rules have been developed to allow for effective communication regarding acids and bases. It is very important that you learn how to name acids and bases—you will encounter them frequently.

Since Arrhenius's original theory does not successfully predict all experimental results, scientists were forced to revise, restrict, or replace the theory. The revised (modified) Arrhenius theory can successfully explain many empirical properties of acids and bases, but it is unable to actually predict whether a particular reaction will take place.

For example, the modified Arrhenius theory cannot predict whether $H_2PO_4^-(aq)$ is an acid or a base. Despite the problems associated with the modified Arrhenius theory, it is still a dramatic improvement over Arrhenius's original theory.

Lesson Glossary

hydronium ion: a hydrated hydrogen ion (proton), $H_3O^+(aq)$; the entity responsible for the acidic properties in an aqueous solution

Lesson 2—Calculating pH and pOH

Get Focused

Left: © Liz Van Steenburgh/shutterstock
Right: © Baloncici/shutterstock

Burritos are a tasty food that can easily be prepared at home. One of the important parts of a burrito is the tortilla, which is made from corn. Corn tortillas were prepared by indigenous North American people and demonstrate one way in which plants native to North America were used.

In the 1400s and 1500s, European explorers learned about the agriculture and diet of the North American peoples. Within a short time, many cultures around the globe readily incorporated corn-based foods. But there was a problem. Illness seemed to arise in areas that relied too heavily on corn sustenance, occasionally reaching epidemic proportions.

These health concerns were a mystery. The indigenous North American people did not display any ill effects from their corn-based diet. So, why were people getting sick? As it turns out, there is a very simple explanation, one that requires knowledge of acid-base chemistry.

Essential Questions

- How do you calculate pH, $[H3O^{+}(aq)]$, pOH, and $[OH^{-}(aq)]$?

Assessment

There is no assignment for Lesson 2.

You must decide what to do with the questions that are not marked by the teacher.

Remember that these questions provide you with the practice and feedback that you need to successfully complete this course. You should respond to all the questions and place those answers in your course folder.

Explore

Read

The pH Scale

In previous science courses, you may have measured and commented on the pH of solutions, but did you really know what that measurement meant? You may recall the following criteria that are often used to classify acidic, basic, and neutral solutions:

If **$[H_3O^+(aq)] = [OH^-(aq)]$**, then the solution is **neutral.**

If **$[H_3O^+(aq)] > [OH^-(aq)]$**, then the solution is **acidic.**

If **$[H_3O^+(aq)] < [OH^-(aq)]$**, then the solution is **basic.**

To learn more about the pH scale and what the values on this scale mean in terms of hydronium-ion and hydroxide-ion concentrations, read pages 238 and 239 of "6.2 pH and pOH Calculations" in your textbook.

Use "Figure 3" on page 239 to answer "Practice" questions 1 to 3. Check your answers with those given at the back of the textbook.

Calculating pH

Read pages 240 to 242 in your textbook. Carefully work through the "SAMPLE problems" and "COMMUNICATION examples" presented, as well as the examples below.

A pH value is an expression of the hydronium-ion concentration for a solution. Since hydronium-ion concentrations are often small, the most convenient way to represent these values is as a negative logarithm. To convert a hydronium-ion concentration into a pH value, the following algorithm is used:

$$pH = -\log\left[H_3O^+(aq)\right]$$

To convert a pH value back into a hydronium-ion concentration, the following algorithm is used:

$$\left[H_3O^+(aq)\right] = 10^{-pH}$$

Earlier, you were asked to express values using the appropriate number of significant digits. The number of digits following the decimal point of a pH value equals the number of significant digits in the hydronium-ion concentration.

Work through the next four examples. Examples 1 and 2 provide a multimedia activity that shows how to perform the calculations using a graphing calculator.

Example 1

A solution has a hydronium-ion concentration of 2.5×10^{-9} mol/L. Calculate the pH of this solution.
Since the hydronium-ion concentration is given, use the formula for pH.

$$pH = -\log\left[H_3O^+(aq)\right]$$

Substitute the hydronium-ion concentration into the formula.

$$\begin{aligned} pH &= -\log\left[H_3O^+(aq)\right] \\ &= -\log\left(2.5 \times 10^{-9}\ \text{mol/L}\right) \\ &= 8.60 \quad \leftarrow \text{2 significant digits} \end{aligned}$$

Go to your Chemistry 20 Multimedia DVD, and choose "Example 1 Calculation" to see how this calculation is performed on the TI-83 Plus graphing calculator.

Example 2

A solution has a pH of 3.5. Determine the hydronium-ion concentration.

Since the pH is given, use the algorithm $\left[H_3O^+(aq)\right] = 10^{-pH}$

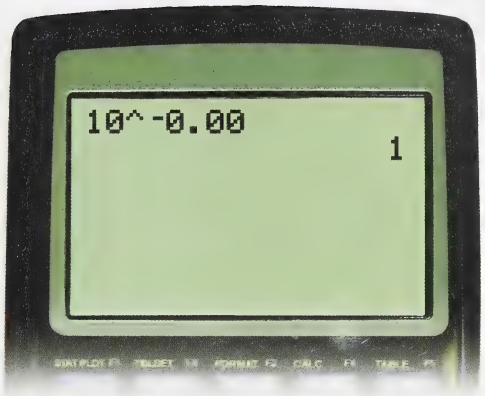
Substitute the pH value into the algorithm.

$$\begin{aligned} \left[H_3O^+(aq)\right] &= 10^{-pH} \\ &= 10^{-3.5}\ \text{mol/L} \quad \leftarrow \text{1 decimal place in pH} \\ &= 3 \times 10^{-4}\ \text{mol/L} \quad \leftarrow \text{1 significant digit} \end{aligned}$$

Go to your Chemistry 20 Multimedia DVD, and choose "Example 2 Calculation" to see how this calculation is performed on the TI-83 Plus graphing calculator.

Example 3

Calculate the hydronium-ion concentration, $[H_3O^+(aq)]$, for a solution with a pH of 0.00.

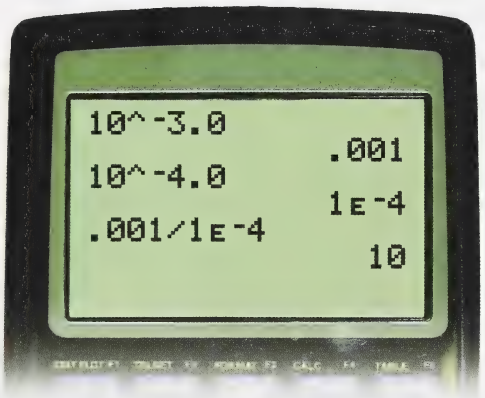


$$\begin{aligned}\left[H_3O^+(aq)\right] &= 10^{-pH} \\ &= 10^{-0.00}\ \text{mol/L} \quad \leftarrow \text{2 decimal places in pH} \\ &= 1.0\ \text{mol/L} \quad \leftarrow \text{2 significant digit}\end{aligned}$$

Example 4

Compare the hydronium-ion concentrations of a solution with a pH of 3.0 with that of a solution with a pH of 4.0.

Step 1: Calculate the hydronium-ion concentration in the solution with a pH of 3.0.



$$\begin{aligned}\left[H_3O^+(aq)\right] &= 10^{-pH} \\ &= 10^{-3.0}\ \text{mol/L} \\ &= 0.001\ \text{mol/L} \quad \leftarrow \text{1 significant digit}\end{aligned}$$

Step 2: Calculate the hydronium-ion concentration in a solution with a pH of 4.0.

$$\frac{\text{pH of 3.0}}{\text{pH of 4.0}} = \frac{0.001\ \text{mol/L}}{0.0001\ \text{mol/L}} = 10$$

Step 3: Determine how many times greater the hydronium-ion concentration is between the two solutions. Divide the greater concentration value by the lesser value.

$$\begin{aligned}\text{pOH} &= -\log\left[OH^-(aq)\right] \\ &= -\log\left(4.52\times10^{-7}\ \text{mol/L}\right) \\ &= 6.345 \quad \leftarrow \text{3 significant digits}\end{aligned}$$

The hydronium-ion concentration of a solution with a pH of 3.0 is ten times greater than the hydronium-ion concentration of a solution with a pH of 4.0.

Self-Check

SC 1. Calculate the pH of a solution with a hydronium-ion concentration of 4.70×10^{-4} mol/L.

SC 2. Determine the hydronium-ion concentration for a solution with a pH of 0.13.

SC 3. Calculate the pH of a solution of hydrobromic acid that has a hydronium-ion concentration of 6.9×10^{-5} mol/L.

SC 4. Is it possible for a solution to have negative pH values or pH values over 14? Use calculations to justify your answer.

Check your work with the answer in the appendix.

Read

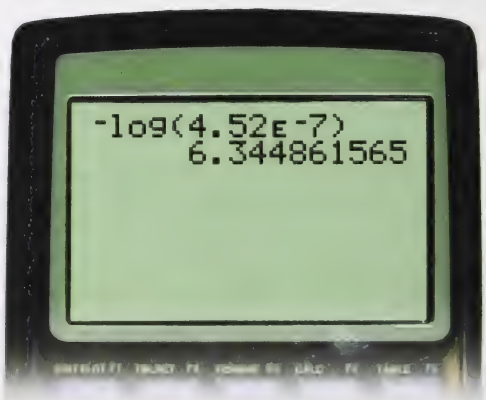
Calculating pOH

Read "pOH and Hydroxide Ion Concentration" on page 243 in your textbook. To practise calculations involving hydroxide-ion concentration and pOH, attempt Communication examples 3 and 4 on page 243.

Example 5

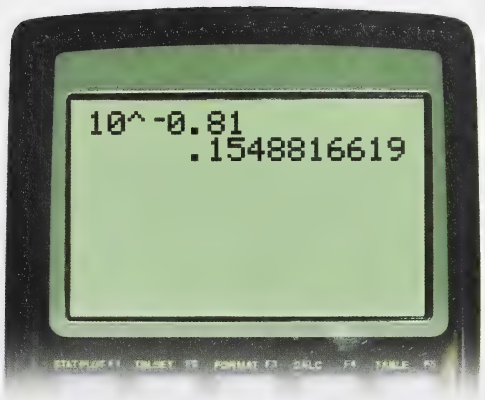
Calculate the pOH of a solution that has a hydroxide-ion concentration of 4.52×10^{-7} mol/L.

$$\begin{aligned} \text{pOH} &= -\log\left[\text{OH}^-(\text{aq})\right] \\ &= -\log\left(4.52 \times 10^{-7}\ \text{mol/L}\right) \\ &= 6.345 \quad \leftarrow \text{3 significant digits} \end{aligned}$$



Example 6

A solution has a pOH of 0.81. Determine the hydroxide-ion concentration.



$$\begin{aligned}[OH^-(aq)] &= 10^{-pOH} \\ &= 10^{-0.81}\ \text{mol/L} \\ &= 0.15\ \text{mol/L} \quad \leftarrow \text{2 significant digits}\end{aligned}$$

Self-Check

SC 5. Calculate the pOH of a solution that has a hydroxide-ion concentration of 3×10^{-8} mol/L.

SC 6. A solution has a pOH of 11.925. Determine the hydroxide-ion concentration.

SC 7. A solution has a pOH of 13.0. Describe the empirical properties of this solution.

Check your work with the answer in the appendix.

Reflect and Connect

© Arlene Jean Gee/shutterstock

At the beginning of this lesson, you learned that indigenous North American people were able to survive very well on a corn-based diet, whereas other cultures did not fare so well. Pellagra is a condition caused by a lack of niacin in the diet. The symptoms of pellagra include "the four D's"—diarrhea, dermatitis, dementia, and death. Niacin, also known as vitamin B3, is critical to cellular metabolism and DNA repair.

When the indigenous North American people prepared their corn for foods, they soaked and cooked the corn in limewater—a basic solution that removes the outer hull of the corn. By removing the hull, the corn could be ground much more effectively, dramatically improving the availability of vitamins and minerals, like niacin, within the corn. Since other cultures did not prepare the corn by soaking it in a basic solution to remove the hull, the foods they ate that were based on corn lacked the necessary nutrients to support their health.

Reflect on the Big Picture

Kitchen Chemistry Project—Using Acids and Bases in Cooking

The use of the basic solution, limewater, to prepare corn is one example of how acids and bases can be used in the preparation of foods. How are acids or bases used in the preparation of the foods you consume?

Find a copy of your favourite recipe, or read the label of something you have eaten recently.

Review the list of ingredients; then do the following:

- Identify at least one acidic or basic substance in the list of ingredients.
- Write the common name, IUPAC name, and the chemical formula for this substance.
- Using a relevant chemical reaction, explain why this substance is used and why the acidic or basic properties of this substance are necessary.

Discuss

Post a copy of your project to the discussion board, and review the work of as many other students as possible. Save a copy of your project to your course folder. You will receive further information from your teacher if your teacher wants you to submit your project for assessment purposes.

Lesson Summary

The following question was investigated in this lesson:

- How do you calculate pH, $[H3O^+(aq)]$, pOH, and $[OH^-(aq)]$?

pH or pOH are logarithmic values that represent the concentration of hydronium ions and concentration of hydroxide ions, respectively, within solutions. These values are used because the concentration of these ions is often very small. The following algorithms can be used to perform calculations involving pH, pOH, and the concentration of their respective ions in solution:

- $pH = -\log[H3O^+(aq)]$
- $[H3O^+(aq)] = 10^{-pH}$
- $pOH = -\log[OH^-(aq)]$
- $[OH^-(aq)] = 10^{-pOH}$

At the beginning of this lesson you learned that the indigenous North American people were able to survive on a corn-based diet due to their ability to use a basic solution to enhance food quality. You also completed a project where you investigated the use of acidic and basic ingredients in the preparation of some of the foods you eat.

Lesson 3—Strength of Acids and Bases

Get Focused

Many people enjoy soft drinks. Although there are many different brands and flavours of soft drinks, they all share one common characteristic—acid.

Two acids—citric acid and phosphoric acid—are commonly used in the preparation of soft drinks. As you may have guessed, these acids are used to influence the taste of the beverage, offsetting its sweetness. But isn't there a risk to ingesting acids? You may also wonder how the presence of these acids influences the pH, and other properties, of soft drinks.

In this lesson you will investigate the acids commonly used in foods, and you will compare them to other acids you have encountered in laboratory experiments.

Essential Questions

- How are the empirical properties of weak acids and bases different from those of strong acids and bases?
- What are polyprotic acids and bases?

Module 5: Lesson 3 Assignment

In this lesson you will complete the Lesson 3 Assignment in the Module 5 Assignment Booklet. Later in the lesson you will receive more information about how to complete this assignment and when to submit it to your teacher.

You must decide what to do with the questions that are not marked by the teacher.

Remember that these questions provide you with the practice and feedback that you need to successfully complete this course. You should respond to all the questions and place those answers in your course folder.

Explore

Try This

The following table contains information about two types of soft drinks—lemon-flavoured and cola. Use this information to answer the questions TR 1 to TR 4.

Soft Drink	Acid	Concentration of Acid	pH of Soft Drink
lemon flavoured	citric acid	0.7% W/V	2.6–2.9
cola	phosphoric acid	0.06% W/V	2.4–2.8

TR 1. Compare the pH of the two types of soft drinks shown in the table. Are the soft drinks of similar acidity? Support your answer by making specific reference to the data shown.

TR 2. Which soft drink contains more acid? By what factor?

TR 3. Calculate the hydronium-ion concentration for each soft drink. Identify which soft drink contains the higher concentration of hydronium ions.

TR 4. Compare the differences between the concentration of acid and the corresponding pH and $[H_3O^+(aq)]$ for each soft drink. Describe whether the data follows an expected correlation or an unexpected correlation. Suggest a possible reason for the correlation shown.

Check your work with the answer in the appendix.

Module 5: Lesson 3 Assignment

You will complete the following lab as part of your Lesson 3 Assignment.

Lab: Comparing Two Acids

Go to your Chemistry 20 Multimedia DVD, and complete the "Comparing Two Acids Virtual Lab," in which ethanoic acid and hydrochloric acid are compared using a variety of diagnostic tests. After completing the investigation, write your answer to the question in Part 1 of your Lesson 3 Assignment.

Read

Strong and Weak Acids

While acids generally demonstrate similar properties, there can be noticeable differences. In the Comparing Two Acids lab, you probably noticed some differences between the behaviour of ethanoic acid and hydrochloric acid. Possibly, the most noticeable difference between the two acid solutions was the intensity of their reaction to magnesium. While magnesium reacts with both acids, the reaction with hydrochloric acid produces bubbles quickly compared to its reaction with ethanoic acid. You may have also noticed that hydrochloric acid is more conductive and has a lower pH compared to ethanoic acid.

Maybe these differences could be due to the hydrochloric acid solution being more concentrated; but by examining the list of materials in the lab, both solutions had identical concentrations. So, what could be the difference between these solutions?

The results from diagnostic tests, such as conductivity and pH, along with the difference in speed of reaction, differentiate acids into two groups—**strong acids** and **weak acids**. Refer to the following table. You may need to review the previous lessons or consult your textbook to refresh your memory about the scientific principles involved with these tests.

Test	Strong Acid*	Weak Acid*
conductivity	**Observation:** highly conductive **Interpretation:** high concentration of ions [H_3O^+(aq) and anions] in solution	**Observation:** slightly conductive **Interpretation:** low concentration of ions [H_3O^+(aq) and anions] in solution
pH	**Observation:** low pH **Interpretation:** higher concentration of H_3O^+(aq); more extensive reaction between solute and water to form H_3O^+(aq)	**Observation:** low pH **Interpretation:** lower concentration of H_3O^+(aq); less extensive reaction between solute and water to form H_3O^+(aq)
reaction with magnesium	**Observation:** quick, vigorous bubbling **Interpretation:** faster rate of reaction; higher concentration of H_3O^+(aq) in the solution	**Observation:** slower, less vigorous bubbling **Interpretation:** slower rate of reaction; lower concentration of H_3O^+(aq) in the solution

* Observations and interpretation are based on tests of solutions containing equal concentrations of strong and weak acids.

While completing the Comparing Two Acids lab, you may have developed a hypothesis relating the differences between strong and weak acids to the extent to which the acids ionize.

Read "Strong and Weak Acids" on pages 254 and 255 of your textbook. As you read this section, summarize what you have learned by writing the definitions for a strong acid and a weak acid. You may wish to compare your summary with the following points.

Summary Point	Definitions	Effects
There is a difference between strength and concentration of an acid or base.	Strength refers to extent of the reaction of the acid or base with water to form hydronium ions, or hydroxide ions, respectively. Concentration refers to the quantity of acid or base particles dissolved in solution. It does not account for how many of these particles actually react with water to form hydronium ions, or hydroxide ions, respectively.	A concentrated solution of a weak acid can have many ionized particles. A dilute solution of a strong acid may contain few ionized particles.

Read

Strong and Weak Bases

Do **strong bases** and **weak bases** exist?

Read "Strong and Weak Bases" on pages 256 and 257 of your textbook. Is the same principle used to differentiate strong and weak acids?

Self-Check

SC 1. Complete "Practice" questions 1 to 5 on page 255 of your textbook.

SC 2. Complete "Practice" questions 6 to 8 on page 257 of your textbook.

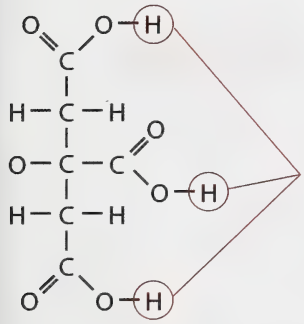
Check your work with the answer in the appendix.

Read

Polyprotic Acids and Bases

Earlier in this lesson you learned that phosphoric acid and citric acid are used to flavour soft drinks. Phosphoric acid, $H_3PO_4(aq)$, has three hydrogen atoms. Each hydrogen is able to react with water, forming a hydronium ion. Citric acid, as shown in the diagram, also contains more than one hydrogen atom that is associated with its acidic behaviour. Acids that have this ability are called **polyprotic acids**.

polyprotic acid: an acid with more than one acidic hydrogen available to react with water to produce hydronium ions



Read "Polyprotic Substances" on page 258 of your textbook for more information about polyprotic acids and polyprotic bases.

Self-Check

SC 3. Carbonic acid, $H_2CO_3(aq)$, is a polyprotic acid that is present in soft drinks. Write two balanced chemical equations that involve carbonic acid and the hydrogen carbonate ion, respectively, with water.

SC 4. The phosphate ion, $PO_4^{3-}(aq)$, can be used in foods to neutralize acids. Use balanced chemical reactions to show the change that can occur within food containing phosphate ions when hydronium ions are also present.

Check your work with the answer in the appendix.

Module 5: Lesson 3 Assignment

Complete the questions located in Part 2 of your Lesson 3 Assignment.

Check with your teacher about whether you should submit your assignment now or wait until all of the Module 5 assignments have been completed.

Reflect and Connect

In this lesson you learned about strong and weak acids and polyprotic acids and bases. Below are two incomplete tables summarizing information presented in this lesson.

Examine these tables. Copy these tables into a separate word-processing document. Using a different colour of text, add additional information to each of these tables. Choose information that you think will be helpful in recalling the information presented in this lesson. The information you add may include definitions, clarifying statements including chemical equations, and examples.

Place a copy of your final versions of these tables into your course folder.

Characteristic	Strong Acid	Weak Acid	Strong Base	Weak Base
Definition	a substance that forms a solution with strong acidic properties	a substance that forms a solution with weak acidic properties Weak acids react incompletely with water (<50%).	a substance that forms a solution with strong basic properties Strong bases are ionic hydroxides.	a substance that forms a solution with weak basic properties Weak bases react partially with water.
Examples	HCl(aq) $H_2SO_4(aq)$ $HNO_3(aq)$	$CH_3COOH(aq)$ $H_2S(aq)$ $H_3PO_4(aq)$	NaOH(aq) KOH(aq) $Ba(OH)_2(aq)$	$CaCO_3(aq)$ $NH_3(aq)$ $Na_2SO_3(aq)$
pH	very low pH	slightly below 7	very high pH	slightly above 7
Conductivity	high	low	high	low
Reaction Rate	fast	slow	fast	slow

Characteristic	Monoprotic Acid	Polyprotic Acid	Monoprotic Base	Polyprotic Base
Definition	an acid that possesses only one ionizable proton	an acid with more than one acidic hydrogen available to react with water to produce hydronium ions	a base that can react only once with water to produce hydroxide ions	a base that can react more than once with water to form hydroxide ions
Examples	$HCl(aq)$ $HNO3(aq)$ $CH3COOH(aq)$	$HOOCCOOH(aq)$ $H3PO4(aq)$ $H2S(aq)$	$NH3(aq)$ $OCl^{-}(aq)$ $CN^{-}(aq)$ $CH3COO^{-}(aq)$	$PO4^{3-}(aq)$ $CO3^{2-}(aq)$ $SO4^{2-}(aq)$ $OOCCOO^{2-}(aq)$
Example of Balanced Chemical Equation				

Lesson Summary

The following critical questions were discussed in this lesson:

- How are the empirical properties of weak acids and bases different from those of strong acids and bases?
- What are polyprotic acids and bases?

Acids and bases have varying properties depending on the degree of ionization or dissociation. A strong acid, such as $HCl(aq)$, and a weak acid, such as $CH3COOH(aq)$, can have different pH values even though the concentration of each acid is the same. Other empirical properties—such as conductivity, pH, and rate of reaction—are more pronounced when comparing solutions containing strong acids than for weak acid solutions with identical solute concentration.

Polyprotic acids and bases may undergo successive reactions with water to produce hydronium ions or hydroxide ions. In the majority of cases, only the first reaction of a polyprotic substance contributes significantly to the overall pH of a solution.

Lesson Glossary

monoprotic acid: an acid that possesses only one ionizable proton and can react only once with water to produce hydronium ions

monoprotic base: a base that can react only once with water to produce hydroxide ions

polyprotic acid: an acid with more than one acidic hydrogen available to react with water to produce hydronium ions

polyprotic base: a base that can react more than once with water to form hydroxide ions

strong acid: a substance that forms a solution with strong acidic properties

Strong acids react completely (>99%) with water to form hydronium ions.

strong base: a substance that forms a solution with strong basic properties

Strong bases are ionic hydroxides that dissociate completely (>99%) to release hydroxide ions.

weak acid: a substance that forms a solution with weak acidic properties

Weak acids react incompletely with water (<50%) to form relatively few hydronium ions.

weak base: a substance that forms a solution with weak basic properties

Weak bases react partially with water (<50%) to produce relatively few hydroxide ions.

Lesson 4—Multi-step pH and pOH Calculations

Get Focused

Baking soda and cream of tartar are common ingredients for baking. These ingredients are used in baking because of the way in which they react with other ingredients. The chemical properties of many of the ingredients found in food contribute to more than just the taste of the food we eat. Often the chemical properties of ingredients are due to their acidic or basic nature. In this lesson you will add to your understanding of acids and bases.

Essential Questions

- How are ionization and dissociation accounted for when calculating the concentration of acidic and basic particles within a solution?
- How can a solution's pH be predicted using information including mass of solute and solution volume?
- Why is the pH of a diluted solution able to be predicted?

Module 5: Lesson 4 Assignment

In this lesson you will complete the Lesson 4 Assignment in the Module 5 Assignment Booklet. Later in the lesson you will receive more information about how to complete this assignment and when to submit it to your teacher.

You will also review and provide constructive criticism of the work of other students in your class and receive feedback on your own work.

You must decide what to do with the questions that are not marked by the teacher.

Remember that these questions provide you with the practice and feedback that you need to successfully complete this course. You should respond to all the questions and place those answers in your course folder.

Explore

Try This: Cream of Tartar

In Lesson 2 of this module you prepared a report describing the purpose for some of the ingredients in your favourite recipes or foods. Cream of tartar is a white powder that is often used when baking. In this activity you will investigate the question: What are the chemical properties of cream of tartar?

Complete the steps in the procedure below. Record your data in a form that will enable you to share it with other students in your class discussion area. Complete the questions below.

Step 1: Obtain three cups or glasses. In the first cup, add 1.25 mL (¼ teaspoon) of baking soda. In the second cup, add 1.25 mL (¼ teaspoon) of cream of tartar. In the third cup, add 1.25 mL (¼ teaspoon) of baking soda and 1.25 mL (¼ teaspoon) of cream of tartar.

Step 2: Add 5 mL (1 teaspoon) of water to the cup with the baking soda. Record your observations.

Step 3: Repeat step 2 by adding 5 mL (1 teaspoon) of water to each of the remaining cups.

Questions:

TR 1. Baking soda is made from sodium hydrogen carbonate, which is known to have basic properties. Predict the chemical nature of cream of tartar. Use your recorded observations to support your prediction.

TR 2. Describe a series of tests you could perform that will confirm your prediction in question TR 1. Include the expected results of these tests that will confirm your prediction.

Include a copy of your observations with your answers to the questions. Post your observations and answers to the Discussion area for your class.

Later in this lesson you will be given further instructions and use the postings of other students to complete the Reflect and Connect activity for this lesson.

Read

Up to now you have investigated many of the properties of acidic and basic solutions. In Module 4 you examined procedures for preparing solutions. What must you consider when preparing acidic or basic solutions of a desired pH or concentration?

Calculating the pH of a Stock Solution

© Image courtesy of Shutterstock.com

The ability to prepare a solution with a specific pH is a necessary skill for laboratory work. Work through the following examples to see how the pH of an acidic or basic solution can be predicted using information including the identity and mass of the solute, as well as total solution volume.

You may wish to refer to information about the preparation and dilution of solutions on pages 803 and 804 in your textbook. You may also want to review information on significant digits and precision on page 814 of your textbook.

Example 1: 2.56 g of hydrogen chloride gas, HCl(g), is dissolved in water to make a 300-mL solution. Calculate the pH of the solution.

Step 1: List the knowns.

$m = 2.56\ \text{g}$

$$M_{HCl} = (M\ \text{of H}) + (M\ \text{of Cl})$$
$$= (1.01\ \text{g/mol}) + (35.45\ \text{g/mol})$$
$$= 36.46\ \text{g/mol}$$

$$V = 300\ \cancel{\text{mL}} \times \frac{1\ \text{L}}{1000\ \cancel{\text{mL}}}$$
$$= 0.300\ \text{L}$$

Step 2: Calculate the number of moles of HCl(g).

$$n = \frac{m}{M}$$
$$= \frac{2.56\ \text{g}}{36.46\ \text{g/mol}}$$
$$= 0.070\,213\,933\,1\ \text{mol}$$

Step 3: Calculate the concentration of HCl(aq).

$$c = \frac{n}{V}$$
$$= \frac{0.070\,213\,933\,1\ \text{mol}}{0.300\ \text{L}}$$
$$= 0.234\,046\,443\,6\ \text{mol/L}$$

Step 4: Determine the concentration of $H_3O^+(aq)$.

$HCl(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$

HCl(aq) is a strong acid. Strong acids ionize completely (react 100% with water). Therefore, the hydronium-ion concentration will be the same as that of HCl(aq).

Step 5: Calculate the pH.

$$\begin{aligned} \text{pH} &= -\log\left[\text{H}_3\text{O}^+(\text{aq})\right] \\ &= -\log(0.234\,046\,443\,6\ \text{mol/L}) \\ &= 0.631 \quad \leftarrow \text{3 significant digits} \end{aligned}$$

The pH of the solution is 0.631.

Example 2: 330 mg of solid barium hydroxide, Ba(OH)2(s), is dissolved in water to make a 600-mL solution. Calculate the pOH of the solution.

Step 1: List the knowns and unknowns.

$$\begin{aligned} m &= 330\ \cancel{\text{mg}} \times \frac{1\ \text{g}}{1000\ \cancel{\text{mg}}} \\ &= 0.330\ \text{g} \end{aligned}$$

$$\begin{aligned} M_{\text{Ba(OH)}_2} &= (M\ \text{of Ba}) + 2(M\ \text{of O}) + 2(M\ \text{of H}) \\ &= (137.33\ \text{g/mol}) + 2(16.00\ \text{g/mol}) + 2(1.01\ \text{g/mol}) \\ &= 171.35\ \text{g/mol} \end{aligned}$$

$$\begin{aligned} V &= 600\ \cancel{\text{mL}} \times \frac{1\ \text{L}}{1000\ \cancel{\text{mL}}} \\ &= 0.600\ \text{L} \end{aligned}$$

Step 2: Calculate the number of moles of Ba(OH)2(s).

$$\begin{aligned} n &= \frac{m}{M} \\ &= \frac{0.330\ \text{g}}{171.35\ \text{g/mol}} \\ &= 0.001\,925\,882\,7\ \text{mol} \end{aligned}$$

Step 3: Calculate the concentration of Ba(OH)2(aq).

$$\begin{aligned} c &= \frac{n}{V} \\ &= \frac{0.001\,925\,882\,7\ \text{mol}}{0.600\ \text{L}} \\ &= 0.003\,209\,804\,5\ \text{mol/L} \end{aligned}$$

Step 4: Calculate the hydroxide-ion concentration [$OH^-(aq)$].

$Ba(OH)_2(aq) \rightarrow Ba^{2+}(aq) + 2\ OH^-(aq)$

$Ba(OH)_2(aq)$ dissociates completely in water, producing two moles of hydroxide ions for each mole of $Ba(OH)_2$ that dissolves. Therefore, the hydroxide-ion concentration will be double that of $Ba(OH)_2(aq)$.

$$\begin{aligned}\left[OH^-(aq)\right] &= 0.003\ 209\ 804\ 5\ \text{mol/L} \times \frac{2_{OH}}{1_{Ba(OH)_2}} \\ &= 0.006\ 419\ 609\ \text{mol/L}\end{aligned}$$

Step 5: Calculate the pOH.

$$\begin{aligned}pOH &= -\log\left[OH^-(aq)\right] \\ &= -\log(0.006\ 419\ 609\ \text{mol/L}) \\ &= 2.192 \quad \leftarrow \text{3 significant digits}\end{aligned}$$

The pOH of the solution is 2.192.

Example 3: Calculate the mass of strontium hydroxide, $Sr(OH)_2(aq)$, required to make a 320-mL solution with a pOH of 4.75.

$pOH = 4.75 \quad \leftarrow$ 2 significant digits

$$\begin{aligned}V &= 320\ \cancel{\text{mL}} \times \frac{1\ \text{L}}{1000\ \cancel{\text{mL}}} \\ &= 0.320\ \text{L}\end{aligned}$$

$$\begin{aligned}M_{Sr(OH)_2} &= (M\ \text{of Sr}) + 2(M\ \text{of O}) + 2(M\ \text{of H}) \\ &= (87.62\ \text{g/mol}) + 2(16.00\ \text{g/mol}) + 2(1.01\ \text{g/mol}) \\ &= 121.64\ \text{g/mol}\end{aligned}$$

Calculate the hydroxide-ion concentration.

$$\begin{aligned}\left[OH^-(aq)\right] &= 10^{-pOH} \\ &= 10^{-4.75}\ \text{mol/L} \\ &= 1.778\ 279\ 41 \times 10^{-5}\ \text{mol/L}\end{aligned}$$

Calculate the concentration of strontium hydroxide.

$Sr(OH)_2(aq) \rightarrow Sr2^+(aq) + 2\ OH^-(aq)$

$Sr(OH)_2(aq)$ dissociates, producing two hydroxide ions for each particle of $Sr(OH)_2$ that dissolves. Therefore, the concentration of $Sr(OH)_2(aq)$ will be half that of $OH^-(aq)$.

$$\begin{aligned} {}^{c}\mathrm{Sr(OH)_2} &= 1.778\,279\,41\times10^{-5}\ \mathrm{mol/L}\,\frac{1_{\mathrm{Ba(OH)_2}}}{2_{\mathrm{OH}}} \\ &= 8.891\,397\,05\times10^{-6}\ \mathrm{mol/L} \end{aligned}$$

Determine the number of moles of $Sr(OH)_2(aq)$.

$$\begin{aligned} c &= \frac{n}{V} \\ n &= cV \\ &= \left(8.891\,397\,05\times10^{-6}\ \mathrm{mol/L}\right)\left(0.320\ \mathrm{L}\right) \\ &= 2.845\,247\,056\times10^{-6}\ \mathrm{mol/L} \end{aligned}$$

Determine the mass of $Sr(OH)_2(s)$.

$$\begin{aligned} n &= \frac{m}{M} \\ m &= nM \\ &= (2.845\,247\,056\times10^{-6}\ \mathrm{mol/L})(121.64\ \mathrm{g/mol}) \\ &= 3.5\times10^{-4}\ \mathrm{g} \\ &= 0.35\ \mathrm{mg} \end{aligned}$$

To make the solution, 0.35 mg of strontium hydroxide is required.

Self-Check

SC 1. 3.10 g of HI(g) is dissolved in water to make a 450-mL solution. Calculate the hydronium-ion concentration and the pH of the solution.

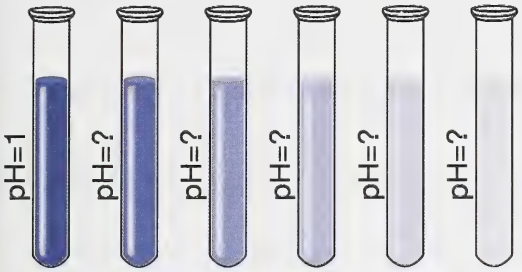
SC 2. 540 mg of solid potassium hydroxide is dissolved in water to make a 700-mL solution. Calculate the pOH of the solution.

SC 3. Calculate the mass of solid barium hydroxide required to make an 80-mL solution with a pOH of 2.65.

Check your work with the answer in the appendix.

Read

Predicting pH of Diluted Solutions



In the previous module you performed a dilution and calculated the resulting concentration of solute in the diluted solution. In your studies you learned that the algorithm to calculate the concentration of the dilute solution depends upon the concentration of solute in the original solution, the volume of original solution taken, and the final volume of the diluted solution.

Earlier in this module you learned that acids react with water to produce hydronium ions. The concentration of hydronium ions in a solution determines the solution's pH. Can the concentration of hydronium ions in a solution be affected by dilution? Is it possible to predict the pH of an acidic solution prepared by the dilution of another acidic solution using the techniques you have already learned? Do the same principles apply for basic solutions?

Example 1: A beaker contains 300 mL of 0.050-mol/L hydrobromic acid. Another beaker contains 700 mL of 0.050-mol/L hydrobromic acid.

a. Compare the pH of the two solutions.

   Only the concentration of an acid affects pH. Since each solution has the same concentration, they will have an identical pH.

b. Calculate the pH of each solution.

   Determine the hydronium-ion concentration.

Hydrobromic acid is a strong acid; therefore, it reacts completely with water producing hydronium ions.

$HBr(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Br^-(aq)$

For each particle of hydrobromic acid dissolved into solution, one hydronium ion is produced. Therefore, the concentration of hydronium ions will be 0.050mol/L.

c. Calculate the pH.

$$\begin{aligned} \text{pH} &= -\log\left[H_3O^+(aq)\right] \\ &= -\log(0.050\ \text{mol/L}) \\ &= 1.30 \quad \leftarrow \text{2 significant digits} \end{aligned}$$

d. Both solutions will have a pH of 1.30, since the pH formula only takes into account the hydronium-ion concentration.

e. Suppose 100 mL of pure water is added to the 300-mL solution. Will the pH increase or decrease?

If 100 mL of pure water is added to the 300-mL solution, the hydronium-ion concentration will decrease because the total volume of solution has increased. The number of hydronium ions did not increase. Therefore, the resulting solution, with respect to hydronium ions, will be more dilute and, thus, have a higher pH.

Example 2: 8.0 mL of 0.30-mol/L HCl(aq) is mixed with 12.0 mL of water.

a. Calculate the hydronium-ion concentration and the pH of the resulting solution.

Calculate the final concentration of the hydrochloric acid using the dilution algorithm.

$c_i = 0.30\ \text{mol/L}$
$V_i = 8.0\ \text{mL}$
$V_f = (8.0 + 12.0)\ \text{mL} = 20.0\ \text{mL}$
$c_f = ?$

$$\begin{aligned} c_iV_i &= c_fV_f \\ c_f &= \frac{c_iV_i}{V_f} \\ &= \frac{(0.30\ \text{mol/L})(8.0\ \cancel{\text{mL}})}{(20.0\ \cancel{\text{mL}})} \\ &= 0.12\ \text{mol/L} \end{aligned}$$

b. Hydrochloric acid is a strong acid. Therefore, the concentration of hydronium ions in the solution is 0.12 mol/L.

Calculate the pH.

$$\begin{aligned} \text{pH} &= -\log\left[H_3O^+(aq)\right] \\ &= -\log(0.12\ \text{mol/L}) \\ &= 0.92 \quad \leftarrow \text{2 significant digits} \end{aligned}$$

c. The pH of the resulting solution is 0.92.

d. If 1.0 mL of the solution produced in part a. is added to 9.0 mL of pure water, calculate the resulting pH of the new solution.

Calculate the final concentration of the hydrochloric acid using the dilution algorithm.

$c_i = 0.12 \text{ mol/L}$
$V_i = 1.0 \text{ mL}$
$V_f = (1.0 + 9.0) \text{ mL} = 10.0 \text{ mL}$
$c_f = ?$

$$c_i V_i = c_f V_f$$
$$c_f = \frac{c_i V_i}{V_f}$$
$$= \frac{(0.12 \text{ mol/L})(1.0 \cancel{\text{mL}})}{(10.0 \cancel{\text{mL}})}$$
$$= 0.012 \text{ mol/L}$$

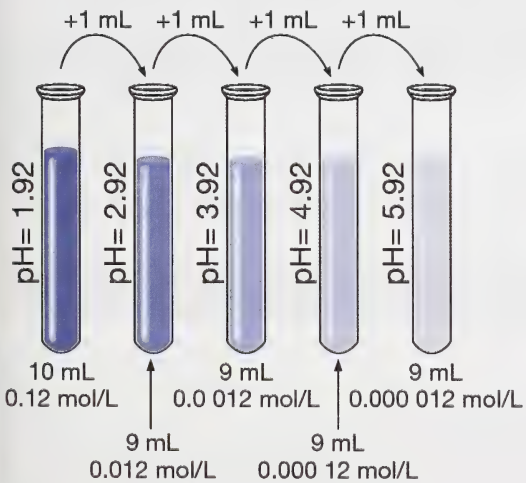
Calculate the pH.

$$\text{pH} = -\log[H_3O^+(aq)]$$
$$= -\log(0.012 \text{ mol/L})$$
$$= 1.92 \quad \leftarrow \text{2 significant digits}$$

The resulting pH is 1.92.

e. Suppose 1.0 mL of the solution from part b. is added to 9 mL of pure water. Predict the resulting pH without doing any calculations.

The pH of this solution will be 2.92. Every time the [H3O$^+$(aq)] decreases by a factor of 10, the pH goes up one full unit since the solution becomes less acidic.



Example 3: A 500-mL sodium hydroxide solution with a pOH of 5.79 is diluted by adding 300 mL of water. Determine the pOH of the diluted solution.

Calculate the hydroxide-ion concentration of the original solution.

$$\left[OH^-(aq)\right] = 10^{-pOH}$$
$$= 10^{-5.79} \text{ mol/L} \leftarrow \text{2 significant digits}$$
$$= 1.621\,810\,097 \times 10^{-6} \text{ mol/L}$$

Calculate the new hydroxide-ion concentration of the dilute solution.

$c_i = 1.621\,810\,097 \times 10^{-6}$ mol/L
$V_i = 500$ mL
$V_f = (500 + 300)$ mL $= 800$ mL
$c_f = ?$

$$c_i V_i = c_f V_f$$
$$c_f = \frac{c_i V_i}{V_f}$$
$$= \frac{(1.621\,810\,097 \times 10^{-6} \text{ mol/L})(500 \cancel{\text{mL}})}{(800 \cancel{\text{mL}})}$$
$$= 1.013\,631\,131\,1 \times 10^{-6} \text{ mol/L}$$

Calculate the new pOH.

$$pOH = -\log\left[OH^-(aq)\right]$$
$$= -\log\left(1.013\,631\,131\,1 \times 10^{-6} \text{ mol/L}\right)$$
$$= 5.99 \leftarrow \text{2 significant digits}$$

The pOH of the diluted solution is 5.99.

Self-Check

SC 4. A beaker contains 400 mL of a 0.070-mol/L solution of perchloric acid, HClO4(aq). Calculate the hydronium-ion concentration and the pH of this solution.

SC 5. 200 mL of a strontium hydroxide solution, Sr(OH)2(aq), with a pOH of 3.92 is diluted by adding 250 mL of water. Determine the pOH of the diluted solution.

SC 6. 14.0 mL of 0.040 mol/L NaOH(aq) is mixed with 60.0 mL of water.

a. Calculate the resulting hydroxide-ion concentration and pOH.

b. If 1.0 mL of the final solution is added to 9.0 mL of pure water, calculate the resulting pOH.

c. Suppose 1.0 mL of the solution from question 6.b. is added to 9 mL of pure water. Predict the resulting pOH without doing any calculations.

Check your work with the answer in the appendix.

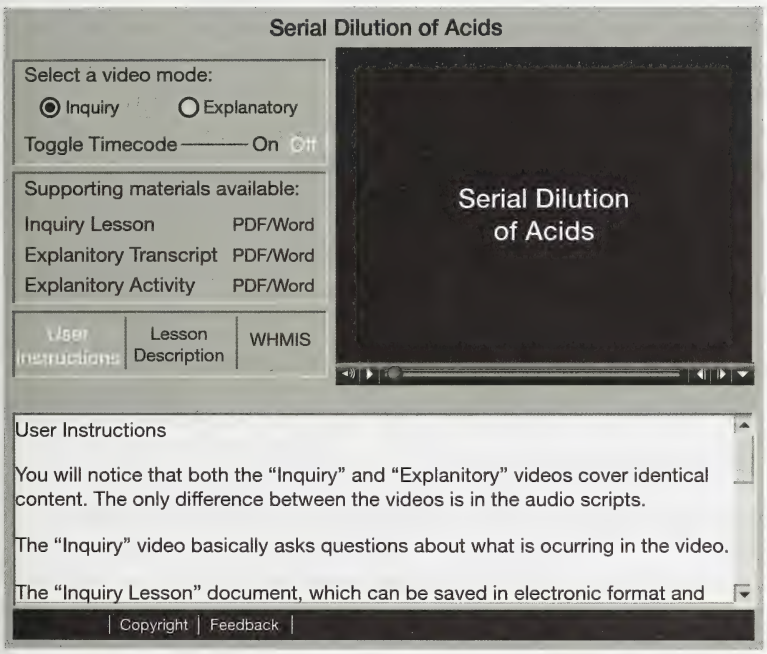
Module 5: Lesson 4 Assignment

You will use the following lab to complete parts of your Lesson 4 Assignment.

Lab: Serial Dilution of Acids

You have used calculations to predict the expected change to the pH of an acidic solution by dilution. To determine whether these changes occur, you will watch a video. Go to **www.learnalberta.ca**. You may be required to input a username and password. Contact your teacher for this information. Enter the search term "dilution" in the search bar. Choose the item called "Serial Dilution of Acids."

Open the video. Located on the left side of the screen, select the "Inquiry" video mode button and set the Toggle Timecode to "On."



Problem

Can the pH of an acidic solution undergoing dilution be predicted?

Part 1: The Technique of Serial Dilutions (00:00 to 04:50)

Watch the first 4 minutes 50 seconds of the video. During the video, questions will be posed by the narrator. To check your answers to these questions, select the "Explanatory" mode button and review the section to hear the answer. Further explanation can be obtained by selecting the "Explanatory Transcript" option.

Answer the questions in Part 1 of the Module 5: Lesson 4 Assignment.

Part 2: The Serial Dilution of HCl(aq) (04:50 to 07:55)

Prepare a table with three columns and five rows. Enter the heading "Solution Concentration" at the top of the first column; enter the heading "Predicted pH" at the top of the second column; and enter the heading "Measured pH" at the top of the third column. Save a copy of your data table to your course folder.

Watch the video from 04:50 to 07:55. Use the "Inquiry" and "Explanatory" features to view this segment to answer questions asked by the narrator. Record the data for the hydrochloric acid solutions shown on the video into the data table.

Answer the questions in Part 2 of the Module 5: Lesson 4 Assignment.

Part 3: The Dilution of $CH_3COOH(aq)$ (07:55 to 08:55)

Prepare a table with three columns and five rows. Enter the heading "Solution Concentration" at the top of the first column; enter the heading "Predicted pH" at the top of the second column; and enter the heading "Measured pH" at the top of the third column. Save a copy of your data table to your course folder.

Watch the video from 07:55 to 08:55. Use the "Inquiry" and "Explanatory" features to view this segment to answer questions asked by the narrator. Record the data for the ethanoic acid solution shown on the video into the data table.

Answer the questions in Part 3 of the Lesson 4 Assignment.

Module 5: Lesson 4 Assignment

Complete the questions located in Part 4 of your assignment.

Check with your teacher about whether you should submit your assignment now or wait until all of the Module 5 assignments have been completed.

Reflect and Connect

Discuss

Read the scoring criteria provided in the General Holistic Scoring Guide. Contact your teacher if you have any questions about the scoring guide.

Generic Holistic Scoring Guide

Score	Criteria
5 Excellent	The student demonstrates an **excellent** understanding of all the **components** of the question and fully and correctly supports those cosmponents. Statements made in the response are organized, unambiguous, and supported explicitly but may contain a minor error or have minor omissions.
4 Good	The student demonstrates a **good** understanding of all the **components** of the question and fully and adequately supports those components. Statements made in the response are unambiguous, mostly complete, and mostly correct but may contain errors.
3 Satisfactory	The student demonstrates a **basic** understanding of the **components** of the question. Statements made in the response may be disorganized, ambiguous, incomplete, and lack support.
2 Limited	The student demonstrates a **limited** understanding of the **components** of the question. Statements made in the response lack details, clarity, and support.
1 Poor	The student provides a solution that contains a relevant statement that begins to answer the question.
0 Insufficient	The response is incorrect and/or totally off topic.
Communication Component • The student produces a clear, unambiguous answer. • The student includes appropriate scientific conventions such as units, significant digits, and states of matter. • The response demonstrates good organizational skills and is presented in a logical manner.	

Go to the Discussion board for your class and download a copy of the data and answers to the preceding Try This activity from one or more students. Read the data and the answers provided in the response.

On the document, enter comments that provide the following feedback to the author:

- One positive comment (or more) identifying an aspect that has been done well. Use the criteria listed in the scoring guide to help you identify this aspect.

- One change that could be made that would improve the quality of the response. Make reference to the criteria in the scoring guide to justify your suggestion.

Post the document containing your comments on the Discussion board, and save a copy to your course folder. Send a copy of your document to your teacher if instructed to do so.

Finally, review the comments from your peers of your own responses to the Try This activity. Revise your responses accordingly, and save a copy of your revised work in your course folder. Submit a second copy of your revised work to your teacher if instructed to do so.

Lesson Summary

The following critical questions were discussed in this lesson:

- How are ionization and dissociation accounted for when calculating the concentration of acidic and basic particles within a solution?
- How can a solution's pH be predicted using information including mass of solute and solution volume?
- Why is the pH of a diluted solution able to be predicted?

By using the algorithms and techniques learned in Modules 4 and 5, it is possible to prepare acidic and basic solutions to desired concentrations and pH.

Formula	Formula may be used when …	Formula may not be used when …
$pH = -\log [H3O^+]$	a. the concentration of a strong acid is given. b. the hydronium-ion concentration is *explicitly stated* in the question, even if it is for a weak or polyprotic acid.	the concentration of a polyprotic acid or a weak acid is given.
$[H3O^+] = 10^{-pH}$	the pH of any solution is given.	
$pH = -\log [OH^-]$	a. the concentration of a strong base is given. b. the hydroxide-ion concentration is *explicitly stated* in the question, even if it is for a weak or polyprotic base.	the concentration of a polyprotic acid or a weak base is given.
$[OH^-] = 10^{-pOH}$	the pOH of any solution is given.	

In situations where concentrated stock solutions of acids and bases are available, dilution of a sample of the stock solution is an alternative. When a stock solution is not available, appropriate quantities of solutes (as solids or gases) must be dissolved. When preparing acidic and basic solutions, you should be very aware of safety concerns and use appropriate techniques for handling these substances.

Lesson 5—Indicators

Get Focused

The last few weeks have been really busy, so now it's time to reconnect with your friends. One way to catch up with friends is to meet and talk while enjoying a cup of tea.

Many people like to add things to their tea, but have you ever considered that a chemical change could result? Lemon juice is a popular thing to add to tea. Lemon juice contains citric acid and other weak acids. In this module you have learned that acids can give food a sour taste.

The cup of tea on the left has a teaspoon of lemon juice. What changes do you observe to the tea inside the cup? You may recall from previous science courses that colour change is one evidence of a chemical reaction. But what component of tea is involved in the reaction and how is lemon juice involved? You may also recall other foods that change colour when exposed to acids or bases.

In this lesson you will study the group of molecules called pH indicators. You will examine how the colour changes that indicators undergo are an example of an acid-base reaction. You will also discover how these compounds can be used to estimate the pH of other solutions.

Essential Questions

- What are acid-base indicators?
- How are acid-base indicators used to predict the pH of a solution?

Module 5: Lesson 5 Assignment

In this lesson you will complete the Lesson 5 Assignment in the Module 5 Assignment Booklet. Later in the lesson you will receive more information about how to complete this assignment and when to submit it to your teacher.

You will also conduct research to identify other substances that could act as pH indicators and design an experiment to test their properties.

You must decide what to do with the questions that are not marked by the teacher.

Remember that these questions provide you with the practice and feedback that you need to successfully complete this course. You should respond to all the questions and place those answers in your course folder.

Explore

Try This

Red cabbage is another food that can change colour depending upon pH. Some of the compounds within the leaves of red cabbage are pH indicators. Follow the procedure below to investigate some of the colours that can be produced by the juice from red cabbage.

Problem

What effect do different substances have on the colour of red cabbage juice?

Procedure

Step 1: Place 2 cups of finely chopped red cabbage in a bowl.

Step 2: Pour boiling water into the bowl, using just enough to cover the red cabbage.

Step 3: After 20 minutes, drain the liquid from the bowl into a glass and set the cabbage aside.

Step 4: On a white plate, place three separate drops of red cabbage juice.

Step 5: Add one drop of lemon juice or vinegar to the first drop of red cabbage juice.

Step 6: Add one drop of water to the second drop of red cabbage juice.

Step 7: Add a pinch of baking soda to the third drop of red cabbage juice.

Observations and Analysis

TR 1. Record your observations in a suitable data table.

TR 2. Explain how the colour changes in red cabbage could not be explained as an effect of dilution of the red cabbage juice.

TR 3. Do you think that red cabbage juice could serve as a readily available substitute for litmus paper?

Check your work with the answer in the appendix.

Read

Read "6.3 Acid-Base Indicators" on pages 245 to 247 of your textbook.

As described in your textbook, the different colours of an indicator correspond to the different forms that indicator molecules can have. You may have noticed that the difference between the two forms, HIn and In-, i

a hydrogen ion, H^+. Can you describe a type of reaction that could be responsible for the loss or gain of an H^+ by a substance?

Earlier in this module you wrote chemical equations describing reactions of acids and bases. You may have noticed that during a reaction, acids lose a hydrogen ion and bases gain a hydrogen ion. Indicators are weak acids and bases that will change form (and colour) in response to the solution in which they are dissolved. In basic solutions, litmus will exist in a form represented by the symbol, Lt^-, which is blue. In acidic solutions, litmus will exist in a form represented by the symbol HLt, which is pink.

So far in this activity you have seen that compounds within tea and red cabbage can act as an **acid-base indicator**. Many indicators exist. Go to your Chemistry 20 Multimedia DVD, and choose the item called "Acid-Base Indicators" to view a table that lists the indicators that are commonly used in laboratories. A similar version of this table appears in the back cover of your textbook.

acid-base indicator: a substance that changes colour in solution when the acidity of the solution changes

Here is a brief explanation of each heading that appears in the Acid-Base Indicators table:

- **Indicator:** Indicators typically have complicated chemical structures—knowledge of which is not required for the majority of chemistry experiments. As such, for simplicity, the common names are used instead of the chemical names.

- **Suggested Abbreviation(s):** The complicated chemical structures are represented using a simple abbreviation. Some indicators, such as methyl violet, have only one hydrogen and are capable of only one colour change (yellow to blue). Other indicators, such as thymol blue, are polyprotic and have multiple colours due to the three possible forms for this molecule:

  H_2Tb (red), HTb^- (yellow) , and Tb^{2-}. (blue)

- **pH Range:** This lists the pH values where the colour of the indicator changes. For example the range for methyl red is 4.8 to 6.0. This means in solutions with a pH below 4.8, methyl red will appear red (HMr); and in solutions with a pH above 6.0, it will appear yellow (Mr^-) . The indicator begins to change its form at the first pH value listed in the range, and all the molecules will have been converted to the other form at the second pH value.

- **Colour Change as pH Increases:** The first colour listed corresponds with the acid form, HIn, of the indicator. The second colour listed corresponds with the basic form, In^-.

- **K_a:** This information is not required in your studies in Chemistry 20.

Self-Check

SC 1. Use the Acid-Base Indicator table to answer Section 6.3 Questions 1(a), 1(b), 1(d), and 2 on page 247 of your textbook.

SC 2. Two drops of orange IV indicator are added to a solution with a pH of 1.3. What is the colour of the indicator?

SC 3. A beaker containing hydrochloric acid has a hydronium-ion concentration of 7.2×10^{-4} mol/L. Determine the colour if a few drops of the following indicators are added to the acid solution.

a. thymol blue
b. methyl orange

SC 4. Thymol blue is added to two beakers containing hydrochloric acid. Determine the colour of the indicato for each of the following concentrations.

a. $[HCl(aq)] = 1.0 \times 10^{-1}$ mol/L
b. $[HCl(aq)] = 1.0 \times 10^{-6}$ mol/L

Check your work with the answer in the appendix.

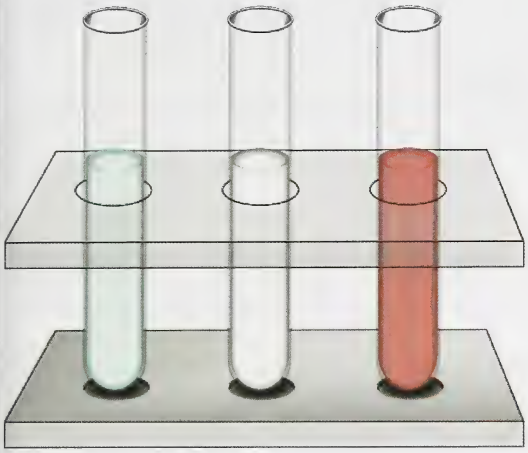
Read

Estimating the pH of Solutions Using Indicators

Indicators can be used as an inexpensive method to estimate the pH of a solution. You may have noticed as you completed the previous Self-Check questions that a single indicator only provides limited information about pH. When estimating pH, more than one indicator is used. Work through the following example to see how indicators are used to estimate the pH of a solution.

Example: A solution is tested with three indicators. The results are summarized in the following table. Estimate the pH of this solution.

Indicator	Colour
bromothymol blue	blue
phenolphthalein	colourless
phenol red	red



Step 1: Use the Acid-Base Indicators table to determine the pH range.

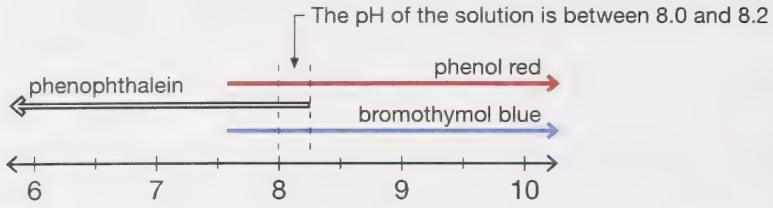
Acid-Base Indicators at 298.15 K

Indicator	Suggested Abbreviation(s)	pH Range	Colour Change as pH Increases	K_a
methyl violet	$HMv(aq)/Mv^-(aq)$	0.0–1.6	yellow to blue	$\sim 2 \times 10^{-1}$
bromothymol blue	$HBb(aq) / Bb^-(aq)$	6.0–7.6	yellow to blue	5.0×10^{-8}
phenol red	$HPr(aq) / Pr^-(aq)$	6.6–8.0	yellow to red	1.0×10^{-8}
phenolphthalein	$HPh(aq) / Ph^-(aq)$	8.2–10.0	colourless to pink	3.2×10^{-10}

According to the table, the three indicators show the following:

- **bromothymol blue:** blue = above pH 7.6
- **phenolphthalein:** colourless = below pH 8.2
- **phenol red:** red = above pH 8.0

Step 2: Use a number line to narrow the range of pH values.



The estimated pH of the solution is between 8.0 and 8.2.

Self-Check

SC 5. Three test tubes with 5 mL of the same solution are in a test tube rack. A different indicator is added to each test tube. Here are the results.

Test Tube	Indicator	Colour
1	phenolphthalein	colourless
2	cresol red	yellow
3	chlorophenol red	red

Use the data to estimate the pH of the solution.

Check your work with the answer in the appendix.

Module 5: Lesson 5 Assignment

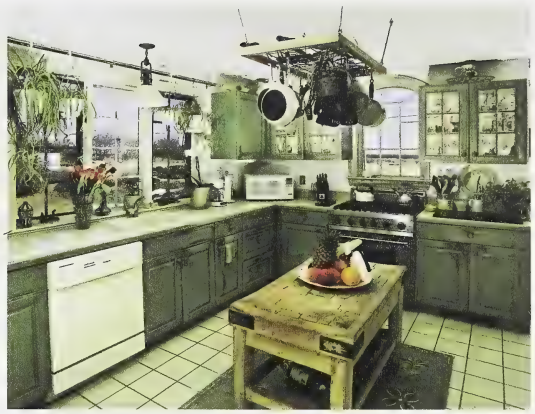
You will use the following lab to complete your Lesson 5 Assignment.

Lab: Measuring pH Using Indicators

Go to your Chemistry 20 Multimedia DVD, and open "Measuring pH Using Indicators Virtual Lab" to estimate the pH of three unknown solutions.

Complete the laboratory questions located in Lesson 5 Assignment as you complete the investigation.

Reflect and Connect



© Judson Abts/shutterstock

Using the Internet or other sources of information, identify a substance found in a kitchen that demonstrates the properties of an acid-base indicator.

Design and perform an experiment that demonstrates how this substance acts as an indicator. Remember to include suitable experimental controls in your design.

Prepare a demonstration that shows how the substance you identified could be used to predict the pH of various solutions found in your home. Use a digital camera or video camera to record the experiment you performed.

If instructed by your teacher, submit the product of your research and experiment to test other common substances that act as indicators. Contact your teacher for a copy of the scoring guide that will be used for this activity.

Lesson Summary

In this lesson you explored the following essential questions:

- What are acid-base indicators?
- How are acid-base indicators used to predict the pH of a solution?

Acid-base indicators are weak acids and bases that can have multiple forms, and each form is associated with a colour. The colour change of one or more indicators can be used to estimate the pH of a solution.

At the beginning of the lesson you made a red cabbage indicator solution that was tested with vinegar and baking soda. When mixed with the vinegar, the solution turned red; when mixed with baking soda, the solution turned a blue-green. The loss of a hydrogen ion by the indicator to the basic hydrogen carbonate ion is responsible for the colour change you observed.

Lesson Glossary

acid-base indicator: a substance that changes colour in solution when the acidity of the solution changes

Module Summary

You have now completed the refrigerator chemistry tour. But before the door is closed, take a look around and observe some other items in the fridge that weren't discussed in this module. Do any of these items have the properties of an acid or a base?

Think back to the questions you were asked at the beginning of the module:

- Scientific theories are human inventions used to explain events that occur in nature and predict future results. While learning acid-base chemistry, you will pay more attention to different theories. What are the limitations of the different theories you will use?

- How do significant digits allow appropriate information about acidic and basic solutions to be communicated?

The Arrhenius theory of acids and bases does not explain observed behaviour of some acids and bases. The original theory proposed by Arrhenius has since been modified as a result of knowledge gained through experimentation after it was initially proposed. In your studies within this unit, you found these theories to be successful in explaining many, but not all, of the acid-base phenomena you observed. In Chemistry 30 you will examine other acid-base theories.

At the completion of this module, you should be able to solve for one of the following using appropriate mathematical relationships: pH, $[H3O^{+}(aq)]$, pOH or $[OHN^{-}(aq)]$. You should also be able to express your answers using appropriate techniques, such as rounding and significant digits.

Module Assessment

The assessment in this module consists of the following:

- Module 5: Lesson 1 Assignment
- Module 5: Lesson 3 Assignment
- Module 5: Lesson 4 Assignment
- Module 5: Lesson 5 Assignment

Unit C Conclusion

In Module 4 you learned that solutions are a special type of mixture—a homogeneous mixture in which a solute dissolves in a solvent. Dissolving involves a formation of intermolecular bonds between the solvent and the solute, leading to observable energy changes. Solubility plays an important role in the dissolving process as well, since some compounds do not dissolve to the same extent as others. Finally, you performed calculations for concentration, dilution, and solution preparation, giving you some of the basic tools required for laboratory work.

At the beginning of this module you were asked, "How can solutions be described qualitatively and quantitatively?" You learned that qualitative descriptions involve the observable properties of a substance, such as colour and smell. Quantitative descriptions involve numerical measurements, such as mass, volume, and solution concentration (moles of solute). A complete understanding of chemistry requires an understanding of both types of relationships. For example, consider the following statement:

- Distilled water is added to a flask of copper(II) sulfate solution. The blue colour becomes more transparent.

This qualitative observation is not particularly useful since there is no way of knowing how blue the solution was initially or how blue it was at the end.

Now consider the following statement:

- 50 mL of distilled water is added to a flask containing 200 mL of 0.1-mol/L copper(II) sulfate solution. The blue colour becomes more transparent as the concentration changes to a value of 0.08 mol/L.

This revised statement is far more useful. Chemists who read a description written this way have enough information to actually recreate the situation and observe the colours themselves. Successful communication of scientific ideas is highly rooted in quantitative measurements for precisely this reason—reproducibility.

In Module 5 you learned that the acidic properties of a solution arise from the presence of aqueous hydronium ions, $H3O^{+}(aq)$, and that basic properties are due to the presence of hydroxide ions, OH–(aq). You also learned that acids and bases may be classified according to different criterion, such as weak, strong, monoprotic, and polyprotic. The main difference between *weak* and *strong* is the degree of ionization, while the difference between *monoprotic* and *polyprotic* is the number of potential successive reactions with water. You learned that chemicals called indicators are useful in measuring pH because they experience a colour change within a very specific range of pH values. In this module you learned to use mathematical formulas to calculate pH, pOH, and the molar concentrations of hydronium and hydroxide ions.

Throughout this module you learned about scientific theories that were developed to explain the behaviour of acids and bases, and tested these theories and identified limitations to theirability to either explain or predict the properties of acidic and basic solutions. This exercise demonstrated the necessity for continuous testing and revision of scientific theories to ensure that they are supported by valid experimental results.

Unit C Assessment

Use the information in this table to answer question A below.

Variables Used to Determine Water Quality

Metals and Ions			
Aluminium	Copper	Molybdenum	Vanadium
Arsenic	Iron	Nickel	Zinc
Beryllium	Lithium	Selenium	Cyanide
Boron	Uranium	Silver	Fluoride
Cadmium	Manganese	Thallium	
Cobalt	Mercury		
Pesticides and Herbicides			
2,4-D	Picloram	Bromoxynil	Chloroprifos
MCPP	Dicamba	Cyanazine	Imazamethabenz
Lindane	Triallate	Malathion	Diuron
Diazanon	Athrazine	Methoxychlor	Dichloprop
Nutrients & Related Variables			
Dissolved Oxygen	Total Phosphorous	Nitrite-Nitrogen	pH
Total Nitrogen	Ammonia		
Bacteria			
Fecal coliforms			
Pharmaceuticals			
Caffeine	Ibuprofen	Ciprofloxacin	

A. Select one of the variables listed in the table above. Explain why the variable you have chosen is useful in assessing the quality of a water sample.

Use the information in this table to answer questions B, C, D, and E below.

Water Quality Data for Selected Sites

Variable	Site 1	Site 2	Site 3	Site 4 (control)
pH	8.2	7.2	7.6	8.2
Metal (Lead) (µg/L)	0.12	1.94	0.60	0.11
Herbicide (Glyphosate) (µg/L)	1.45	0.02	0.50	0.02
Pharmaceuticals (Ibuprofen) (µg/L)	0.01	0.01	1.7	0.00

B. Explain the purpose of the control in the data table. Describe a suitable location where the control water samples could be obtained.

C. Use the data from the table above to complete the chart below. Match each of the sites numbered above to one of the descriptions of the sampling site below. Explain the reasoning behind one of your choices by making specific reference to the data provided.

Site	Description of sampling site
	Downstream from large city
	Dugout pond on agricultural land
	Tailings pond in industrial area

D. Compare the difference in the acidity between Sites 1 and 2. Comment on the magnitude difference between the water samples collected from the two sites and its possible implications for the local ecosystem.

E. The values shown in the table represent different ways to express the concentration of solute within solution. What other units could be used to express the concentration of the different substances shown in this table? Provide a justification for your choice.

Discussion Rubric

Score	Criteria
5 Excellent	The student demonstrates an **excellent** understanding of all the **components** of the question and fully and correctly supports those components. Statements made in the response are organized, unambiguous, and are supported explicitly, but may contain a minor error or have minor omissions.
4 Good	The student demonstrates a **good** understanding of all the **components** of the question and fully and adequately supports those components. Statements made in the response are unambiguous, mostly complete, mostly correct, but may contain errors.
3 Satisfactory	The student demonstrates a **basic** understanding of the **components** of the question. Statements made in the response may be disorganized, ambiguous, incomplete, and may lack support.
2 Limited	The student demonstrates a **limited** understanding of the **components** of the question. Statements made in the response lack details, clarity, and support.
1 Poor	The student provides a solution that contains relevant statements that begin to answer the question.
0 Insufficient	The response is incorrect and/or totally off topic.

Module Glossary

acid-base indicator: a substance that changes colour in solution when the acidity of the solution changes

hydronium ion: a hydrated hydrogen ion (proton), $H_3O^+(aq)$; the entity responsible for the acidic properties in an aqueous solution

monoprotic acid: an acid that possesses only one ionizable proton and can react only once with water to produce hydronium ions

monoprotic base: a base that can react only once with water to produce hydroxide ions

polyprotic acid: an acid with more than one acidic hydrogen available to react with water to produce hydronium ions

polyprotic base: a base that can react more than once with water to form hydroxide ions

strong acid: a substance that forms a solution with strong acidic properties

Strong acids react completely (>99%) with water to form hydronium ions.

strong base: a substance that forms a solution with strong basic properties

Strong bases are ionic hydroxides that dissociate completely (>99%) to release hydroxide ions.

weak acid: a substance that forms a solution with weak acidic properties

Weak acids react incompletely with water (<50%) to form relatively few hydronium ions.

weak base: a substance that forms a solution with weak basic properties

Weak bases react partially with water (<50%) to produce relatively few hydroxide ions.

Lesson 1

TR 1. The proposed chemical equation is correct. A gas is produced, as indicated by the equation, along with neutral products. This is consistent with the definition for an acid-base reaction.

Further tests may include a litmus test—to determine whether the products are acidic, basic, or neutral—and a limewater test—to identify whether the gas produced is carbon dioxide (limewater turns cloudy = carbon dioxide present).

Self-Check Answers

Lesson 1

SC 1.

Conductivity: It's useful for separating out neutral molecular solutions, but it cannot distinguish between acids, bases, and neutral ionic solutions.

Litmus: It can be used to distinguish between acids, bases, and neutral solutions, but it does not give an exact pH value.

Taste: Taste may be used to recognize acids and dissolved salts (such as table salt), but solutions must never be tasted in the lab for safety reasons.

Feel: Feel may help distinguish between an acid and a base, but, again, this should never be carried out in a lab for safety reasons.

pH: The pH of a solution can be used to distinguish between acids, bases, and neutral solutions, but it requires the use of indicators (which you will learn later in this module) or an expensive pH meter.

SC 2.

a. $HF(g) \rightarrow H^{+}(aq) + F^{-}(aq)$, ionization
b. $Ba(OH)2(s) \rightarrow Ba^{2+}(aq) + 2\ OH^{-}(aq)$, dissociation
c. $HNO3(aq) \rightarrow H^{+}(aq) + NO3^{-}(aq)$, ionization
d. $H2SO4(aq) \rightarrow 2\ H^{+}(aq) + SO4^{2-}(aq)$, ionization

SC 3.

Common Name	Systematic IUPAC Name	Formula
boric acid	aqueous hydrogen borate	$H_3BO_3(aq)$
benzoic acid	benzoic acid	**$C_6H_5COOH(aq)$**
barium hydroxide	barium hydroxide	**$Ba(OH)_2(aq)$**
phosphoric acid	aqueous hydrogen phosphate	$H_3PO_4(aq)$
hydrosulfuric acid	aqueous hydrogen sulfide	**$H_2S(aq)$**
chlorous acid	aqueous hydrogen chlorite	$HClO_2(aq)$
hydroiodic acid	aqueous hydrogen iodide	**HI(aq)**
carbonic acid	aqueous hydrogen carbonate	**$H_2CO_3(aq)$**
nitrous acid	aqueous hydrogen nitrite	$HNO_2(aq)$
hydrofluoric acid	aqueous hydrogen fluoride	HF(aq)
acetic acid	**ethanoic acid**	**$CH_3COOH(aq)$**
chromic acid	aqueous hydrogen chromate	$H_2CrO_4(aq)$
sulfurous acid	aqueous hydrogen sulfite	**$H_2SO_3(aq)$**
sodium hydrogen carbonate	**sodium hydrogen carbonate**	$NaHCO_3(aq)$

SC 4. "Practice" questions 1 and 2 on page 251

1.

a. $HI(aq) + H_2O(aq) \rightarrow H_3O^+(aq) + I^-(aq)$

A reaction with water produces a hydronium ion, making the solution acidic.

b. $HOCl(aq) + H_2O(aq) \rightarrow H_3O^+(aq) + OCl^-(aq)$

A reaction with water produces a hydronium ion, making the solution acidic.

c. $H_3PO_4(aq) + H_2O(aq) \rightarrow H_3O^+(aq) + H_2PO_4^-(aq)$

A reaction with water produces a hydronium ion, making the solution acidic.

2.

a. $Na_2SO_4(aq)$ dissociates into sodium ions and sulfate ions. Sulfate ions can react with water to form hydroxide ions, as shown in the following reaction:

$$SO_4^{2-}(aq) + H_2O(aq) \rightarrow HSO_4^-(aq) + OH^-(aq)$$

b. $NaCH_3COO(aq)$ dissociates into sodium ions and ethanoate ions. Ethanoate ions can react with water to form hydroxide ions, as shown in the following reaction:

$$CH_3COO^-(aq) + H_2O(aq) \rightarrow CH_3COOH(aq) + OH^-(aq)$$

c. $Sr(OH)_2(aq)$ dissociates into strontium ions and hydroxide ions.

$$Sr(OH)_2(aq) \rightarrow Sr^{2+}(aq) + 2\ OH^-(aq).$$

Pre-Lab Answers

Lesson 1

1. $H^+(aq)$ and $OH^-(aq)$

2. The concepts of dissociation and of ionization are the mechanisms by which $H^+(aq)$ and $OH^-(aq)$ are produced and can be present in aqueous solutions.

In solutions where the concentration of $H^+(aq)$ is greater than the concentration of $OH^-(aq)$, it will have properties consistent with an acid.

In solutions where the concentration of $H^+(aq)$ is less than the concentration of $OH^-(aq)$, it will have properties consistent with a base.

In solutions where the concentration of $H^+(aq)$ is equal to the concentration of $OH^-(aq)$, it will have properties consistent with a neutral solution.

SC 5.

Theory	Acidic Particle	Basic Particle	Mechanism to Form Particles
Arrhenius's original theory	$H^+(aq)$	$OH^-(aq)$	• dissociation (hydroxide) • ionization (acids)
Arrhenius's modified theory	$H_3O^+(aq)$	$OH^-(aq)$	• dissociation (for ionic hydroxides) • reaction with water molecules (for acids or bases, explains ionization)

SC 6. A hydrogen ion is simply a positively charged proton, whereas a hydronium ion is a water molecule that has incorporated an extra hydrogen atom. A similarity between the two is that they both have a charge of 1+.

SC 7.

a. $HNO_3(aq) + H_2O(l) \rightarrow NO_3^-(aq) + H_3O^+(aq)$

b. $HBr(aq) + H_2O(l) \rightarrow Br^-(aq) + H_3O^+(aq)$

c. $Na_2HPO_4(s) \rightarrow 2\ Na^+(aq) + HPO_4^{2-}(aq)$

$HPO_4^{2-}(aq) + H_2O(l) \rightarrow PO_4^{3-}(aq) + H_3O^+(aq)$

d. $Na_2HPO_4(s) \rightarrow 2\ Na^+(aq) + HPO_4^{2-}(aq)$

$HPO_4^{2-}(aq) + H_2O(l) \rightarrow H_2PO^{4-}(aq) + OH^-(aq)$

e. $Ca(OH)_2(s) \rightarrow Ca^{2+}(aq) + 2\ OH^-(aq)$

f. $NaCN(s) \rightarrow Na^+(aq) + CN^-(aq)$

$CN–(aq) + H_2O(l) \rightarrow HCN(aq) + OH–(aq)$

C 8. The first reaction involves dissociation of the solid ionic compound.

$$NaHCO_3(s) \rightarrow Na^+(aq) + HCO_3^-(aq)$$

he second reaction involves a reaction between the hydrogen carbonate ion and a water molecule.

$$HCO_3^-(aq) + H_2O(l) \rightarrow H_2CO_3(aq) + OH^-(aq)$$

The products of the second reaction, specifically the hydroxide ion, are consistent with the observed basic properties for the solution.

SC 9. $HNO_2(aq) + H_2O(l) \rightarrow NO_2^-(aq) + H_3O^+(aq)$

$NaOH(aq) \rightarrow Na^+(aq) + OH^-(aq)$

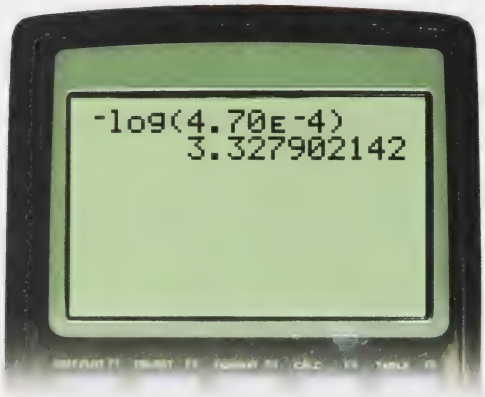
$H_3O^+(aq) + OH^-(aq) \rightarrow 2\ H_2O(l)$

Lesson 2

SC 1.

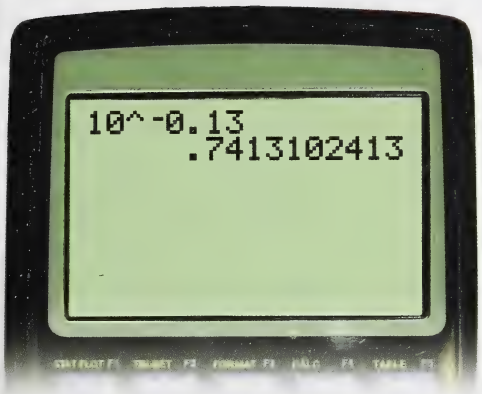
$$\begin{aligned} pH &= -\log\left[H_3O^+(aq)\right] \\ &= -\log\left(4.70\times10^{-4}\ \text{mol/L}\right) \\ &= 3.328 \end{aligned}$$

← 3 significant digits



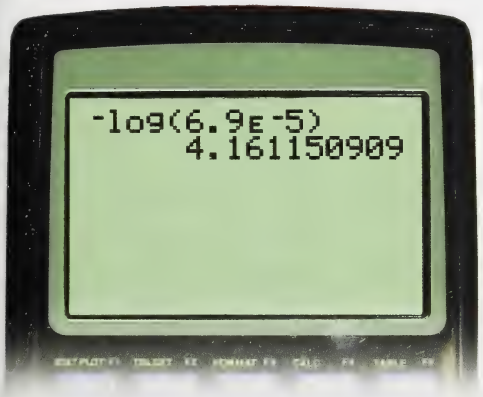
SC 2.

$$\left[H_3O^+(aq)\right] = 10^{-pH}$$
$$= 10^{-0.13} \text{ mol/L}$$
$$= 0.74 \text{ mol/L} \leftarrow \text{2 significant digits}$$



SC 3.

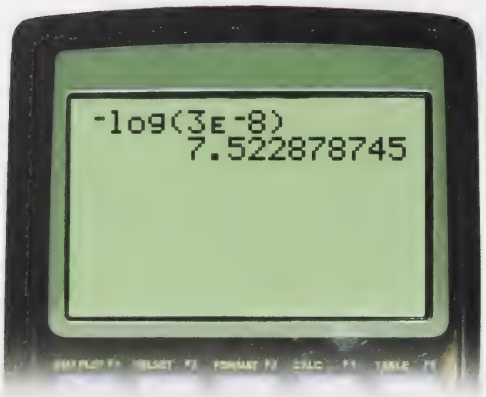
$$pH = -\log\left[H_3O^+(aq)\right]$$
$$= -\log\left(6.9\times10^{-5} \text{ mol/L}\right)$$
$$= 4.16 \leftarrow \text{2 significant digits}$$



C 4. Yes. A solution with a negative pH value has a hydronium-ion concentration that is greater than 1.0 ol/L. A solution with a pH value over 14 has a hydronium-ion concentration that is less than 1.0×10^{-14} ol/L. Both concentrations are possible.

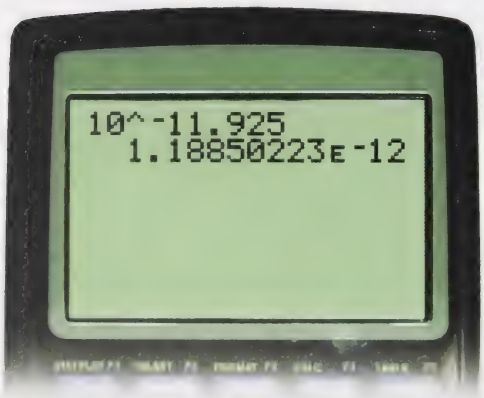
SC 5.

$$\begin{aligned} \text{pOH} &= -\log\left[\text{OH}^-(\text{aq})\right] \\ &= -\log\left(3\times10^{-8}\ \text{mol/L}\right) \\ &= 7.5 \quad \leftarrow \text{1 significant digit} \end{aligned}$$



SC 6.

$$\begin{aligned} \left[\text{OH}^-(\text{aq})\right] &= 10^{-\text{pOH}} \\ &= 10^{-11.925}\ \text{mol/L} \\ &= 1.19\times10^{-12}\ \text{mol/L} \quad \leftarrow \text{3 significant digits} \end{aligned}$$



SC 7. A solution with a pOH of 13.0 will be very acidic in nature. If a pOH of 1.0 is very basic, the other en of the scale will be acidic. The properties will be consistent with those of an acidic solution—sour taste, reac with metals, and turns blue litmus red.

Try This Answers

Lesson 3

TR 1. Data may be compared using either of the following values:

Type of soft drink	Average pH	Approximate $[H_3O^+(aq)]$*
Lemon-flavoured	2.8	1.5×10^{-3} mol/L
Cola	2.6	2.5×10^{-3} mol/L

* Calculated using average pH

The pH values of the two soft drinks are quite similar in that they only differ by 0.2. Therefore, they have similar acidity in relation to the pH scale. The concentration of hydronium ions in each soft drink is similar since the values are of the same order of magnitude (exponent).

TR 2. The lemon-flavoured soft drink contains over ten times more acid than the cola.

$$\frac{\text{lemon-flavoured acid concentration}}{\text{cola acid concentration}} = \frac{0.7\%\ \text{W/V}}{0.06\%\ \text{W/V}} = 12$$

TR 3. Refer to the table in the answer to question TR 1. The cola contains the higher hydronium-ion concentration.

TR 4. The soft drink with the higher concentration of acid has a higher pH. This result is not the expected correlation. A greater concentration of acid should result in a higher concentration of hydronium ions, formed by the reaction of the acid with water molecules. A possible explanation is that fewer citric acid particles react with water to form hydronium ions compared to phosphoric acid particles.

SC 1. "Practice" questions 1 to 5, page 255

1. **Test 1:** If an acidic solution is tested for conductivity and it is highly conductive, then it contains a high concentration of ions [H3O+(aq) and anions] and is a strong acid. If the conductivity is low, then it contains few ions, and is a weak acid.

   Test 2: If an acidic solution is tested for pH and it has a low pH, then it contains a high concentration of hydronium ions and is a strong acid. If the pH is high, the solution contains few hydronium ions and is a weak acid.

2. The key idea used to explain the difference between strong and weak acids is the extent of the reaction (ionization) of the acid solute with water.

3. Examples of strong acids include hydrochloric acid, hydroiodic acid, sulfuric acid, nitric acid, perchloric acid, and hydrobromic acid.

4. a. Hydrochloric acid is a strong acid. Since all strong acids ionize completely (more than 99%), the concentration of hydronium ions produced is 0.15 mol/L.

$HCl(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$

$$\left[H_3O^+(aq)\right] = 0.15 \text{ mol/L} \times \frac{1_{H_3O}}{1_{HCl}} = 0.15 \text{ mol/L}$$

b. $$\begin{aligned} pH &= -\log\left[H_3O^+(aq)\right] \\ &= -\log(0.15 \text{ mol/L}) \\ &= 0.82 \end{aligned}$$

5. Acetic acid is a weak acid and will not ionize completely like hydrochloric acid will. Therefore, a 0.15-mol/L solution of acetic acid will produce a solution containing less than 0.15 mol/L of hydronium ions. Since the concentration of hydronium ions in the acetic acid solution is lower than that of the hydrochloric acid solution, the acetic acid solution should have a pH that is higher than 0.82.

SC 2. "Practice" questions 6 to 8, page 257

6. Two possible diagnostic tests and their results are shown below for two basic solutions of equal molar concentration:

Test	Strong Base	Weak Base
conductivity	highly conductive due to complete dissociation and ionization	lower conductivity due to less ionization
pH	very high pH (as expected if nearly all the solute dissociates or ionizes)	lower pH (less than complete ionization)

7. Strong bases would have a lower pOH value compared to a weak base with equal concentration of solute (if factors like temperature and concentration were controlled).

8. a. Strong bases are all ionic compounds that contain the hydroxide ion, $OH^-(aq)$

b. If you have to explain the basic properties of the substance (presence of hydroxide ion as a product) using a reaction with water rather than by dissociation, the substance is a weak base.

SC 3.

Reaction 1: $H_2CO_3(aq) + H_2O(l) \rightarrow HCO_3^-(aq) + H_3O^+(aq)$

Reaction 2: $HCO_3^-(aq) + H_2O(l) \rightarrow CO_3^{2-}(aq) + H_3O^+(aq)$

SC 4.

Three reactions are possible because phosphate ion is a polyprotic base.

Reaction 1: $PO4^{3-}(aq) + H3O^{+}(aq) \rightarrow HPO4^{2-}(aq) + H2O(l)$

Reaction 2: $HPO4^{2-}(aq) + H3O^{+}(aq) \rightarrow H2PO4^{-}(aq) + H2O(l)$

Reaction 3: $H2PO4^{-}(aq) + H3O^{+}(aq) \rightarrow H3PO4(aq) + H2O(l)$

Lesson 4

SC 1.

Step 1: List the knowns.

$$\begin{aligned} M_{HI} &= (M \text{ of H}) + (M \text{ of I}) \\ &= (1.01 \text{ g/mol}) + (126.90 \text{ g/mol}) \\ &= 127.91 \text{ g/mol} \end{aligned}$$

$$\begin{aligned} V &= 450 \cancel{\text{mL}} \times \frac{1 \text{ L}}{1000 \cancel{\text{mL}}} \\ &= 0.450 \text{ L} \end{aligned}$$

Step 2: Calculate the number of moles of HI(g).

$$\begin{aligned} n &= \frac{m}{M} \\ &= \frac{3.10 \text{ g}}{127.91 \text{ g/mol}} \\ &= 0.024\,235\,790\,8 \text{ mol} \end{aligned}$$

Step 3: Calculate the concentration of HI(g).

$$\begin{aligned} c &= \frac{n}{V} \\ &= \frac{0.024\,235\,790\,8 \text{ mol}}{0.450 \text{ L}} \\ &= 0.053\,857\,312\,9 \text{ mol/L} \end{aligned}$$

Step 4: Calculate the hydronium-ion concentration, $[H3O^{+}(aq)]$.

$HI(aq) + H2O(l) \rightarrow H3O^{+}(aq) + I^{-}(aq)$

HI(aq) is a strong acid and completely ionizes in water. Therefore, the hydronium-ion concentration will be the same as that of HI(aq), which is 0.0539 mol/L.

Step 5: Calculate the pH.

$$\begin{aligned}\text{pH} &= -\log\left[\text{H}_3\text{O}^+(\text{aq})\right] \\ &= -\log(0.053\ 857\ 312\ 9\ \text{mol/L}) \\ &= 1.269 \quad \leftarrow \text{ 3 significant digits}\end{aligned}$$

The hydronium-ion concentration of the solution is 0.0539 mol/L and the pH is 1.269.

SC 2.

$$\begin{aligned}m &= 540\ \cancel{\text{mg}} \times \frac{1\ \text{g}}{1000\ \cancel{\text{mg}}} \\ &= 0.540\ \text{g}\end{aligned}$$

$$\begin{aligned}M_{\text{KOH}} &= (M\ \text{of K}) + (M\ \text{of O}) + (M\ \text{of H}) \\ &= (39.10\ \text{g/mol}) + (16.00\ \text{g/mol}) + (1.01\ \text{g/mol}) \\ &= 56.11\ \text{g/mol}\end{aligned}$$

$$\begin{aligned}V &= 700\ \cancel{\text{mL}} \times \frac{1\ \text{L}}{1000\ \cancel{\text{mL}}} \\ &= 0.700\ \text{L}\end{aligned}$$

Calculate the number of moles of KOH(s).

$$\begin{aligned}n &= \frac{m}{M} \\ &= \frac{0.540\ \text{g}}{56.11\ \text{g/mol}} \\ &= 0.009\ 623\ 952\ 9\ \text{mol}\end{aligned}$$

Calculate the concentration of KOH(aq).

$$\begin{aligned}c &= \frac{n}{V} \\ &= \frac{0.009\ 623\ 952\ 9\ \text{mol}}{0.700\ \text{L}} \\ &= 0.013\ 748\ 504\ 2\ \text{mol/L}\end{aligned}$$

Determine the concentration of $OH^-(aq)$ in solution.

$$\text{KOH(aq)} \rightarrow \text{K}^+(\text{aq}) + \text{OH}^-(\text{aq})$$

A 1-to-1 ratio exists between KOH(aq) and the hydroxide ion. Therefore, the hydroxide-ion concentration is the same as that of KOH(aq).

Calculate the pOH.

$$\begin{aligned}\text{pOH} &= -\log\left[\text{OH}^-(\text{aq})\right] \\ &= -\log(0.013\,748\,504\,2\ \text{mol/L}) \\ &= 1.862 \quad \leftarrow \text{3 significant digits}\end{aligned}$$

The pOH of the solution is 1.862.

SC 3.

$\text{pOH} = 2.65 \quad \leftarrow$ 2 significant digits

$$V = 80\ \cancel{\text{mL}} \times \frac{1\ \text{L}}{1000\ \cancel{\text{mL}}}$$
$$= 0.080\ \text{L}$$

$$\begin{aligned}M_{\text{Ba(OH)}_2} &= (M\ \text{of Ba}) + 2(M\ \text{of O}) + 2(M\ \text{of H}) \\ &= (137.33\ \text{g/mol}) + 2(16.00\ \text{g/mol}) + 2(1.01\ \text{g/mol}) \\ &= 171.35\ \text{g/mol}\end{aligned}$$

Calculate the hydroxide-ion concentration of the solution.

$$\begin{aligned}\left[\text{OH}^-(\text{aq})\right] &= 10^{-\text{pOH}} \\ &= 10^{-2.65}\ \text{mol/L} \\ &= 0.002\,238\,7211\ \text{mol/L}\end{aligned}$$

Calculate the concentration of barium hydroxide.

$\text{Ba(OH)2(aq)} \rightarrow \text{Ba2+(aq)} + 2\ \text{OH}^-\text{(aq)}$

A 1-to-2 ratio exists between Ba(OH)2(aq) and the hydroxide ion. Therefore, the concentration of Ba(OH)2(aq) will be half that of barium hydroxide.

$$\begin{aligned}{}_{\text{Ba(OH)}_2} &= 0.002\,238\,721\,1\ \text{mol/L} \times \frac{1}{\frac{\text{Ba(OH)}_2}{2_{\text{OH}}}} \\ &= 0.001\,119\,360\,6\ \text{mol/L}\end{aligned}$$

Determine the number of moles of Ba(OH)2(aq).

$$c = \frac{n}{V}$$
$$n = cV$$
$$= (0.001\ 119\ 360\ 6\ \text{mol/L})(0.080\ \text{L})$$
$$= 8.954\ 884\ 554 \times 10^{-5}\ \text{mol}$$

Determine the mass of Ba(OH)2(s).

$$n = \frac{m}{M}$$
$$m = nM$$
$$= (8.954\ 884\ 554 \times 10^{-5}\ \text{mol})(171.35\ \text{g/mol})$$
$$= 0.015\ \text{g or } 15\ \text{mg}$$

The mass of barium hydroxide required is 0.15 g or 15 mg.

SC 4. Only the concentration has an effect on pH. Therefore, in this particular question, the volume (400 mL) is irrelevant.

Determine the hydronium-ion concentration.

$$HClO4(aq) + H2O(l) \rightarrow H3O^{+}(aq) + ClO4^{-}(aq)$$

A 1-to-1 ratio exists between HClO4(aq) and H3O+(aq). Therefore, the hydronium-ion concentration will be 0.070 mol/L.

Calculate the pH.

$$pH = -\log[H_3O^{+}(aq)]$$
$$= -\log(0.070\ \text{mol/L})$$
$$= 1.15 \leftarrow \text{2 significant digits}$$

The pH of the solution is 1.15.

SC 5. Calculate the hydroxide-ion concentration of the original solution.

$$[OH^{-}(aq)] = 10^{-\text{pOH}}$$
$$= 10^{-3.92}\ \text{mol/L} \leftarrow \text{2 significant digits}$$
$$= 1.202\ 264\ 435 \times 10^{-4}\ \text{mol/L}$$

Calculate the new hydroxide-ion concentration of the dilute solution.

$$c_i = 1.202\,264\,435 \times 10^{-4}\ \text{mol/L}$$
$$V_i = 200\ \text{mL}$$
$$V_f = (200 + 250)\ \text{mL} = 450\ \text{mL}$$
$$c_f = ?$$

$$c_i V_i = c_f V_f$$
$$c_f = \frac{c_i V_i}{V_f}$$
$$= \frac{(1.202\,264\,435 \times 10^{-4}\ \text{mol/L})(200\ \cancel{\text{mL}})}{(450\ \cancel{\text{mL}})}$$
$$= 5.343\,397\,487 \times 10^{-5}\ \text{mol/L}$$

Calculate the new pOH.

$$\text{pOH} = -\log[\text{OH}^-(\text{aq})]$$
$$= -\log(5.343\,397\,487 \times 10^{-5}\ \text{mol/L})$$
$$= 4.27 \leftarrow \text{2 significant digits}$$

The pOH of the diluted solution is 4.27.

C 6.

a. Calculate the final concentration of the sodium hydroxide solution.

$$c_i = 0.040\ \text{mol/L}$$
$$V_i = 14.0\ \text{mL}$$
$$V_f = (14.0 + 60.0)\ \text{mL} = 74.0\ \text{mL}$$
$$c_f = ?$$

$$c_i V_i = c_f V_f$$
$$c_f = \frac{c_i V_i}{V_f}$$
$$= \frac{(0.040\ \text{mol/L})(14.0\ \cancel{\text{mL}})}{(74.0\ \cancel{\text{mL}})}$$
$$= 0.007\,567\,567\,6\ \text{mol/L}$$

Because sodium hydroxide dissociates completely, the hydroxide-ion concentration in the solution is 0.0076 mol/L.

Calculate the pOH.

$$\begin{aligned}\text{pOH} &= -\log\left[\text{OH}^-(\text{aq})\right] \\ &= -\log(0.007\,567\,567\,6\ \text{mol/L}) \\ &= 2.12 \quad \leftarrow \text{ 2 significant digits}\end{aligned}$$

The pOH of the resulting solution is 0.92.

b. Calculate the final concentration of hydroxide ions.

$$\begin{aligned}c_\text{i} &= 0.007\,567\,567\,6\ \text{mol/L} \\ V_\text{i} &= 1.0\ \text{mL} \\ V_\text{f} &= (1.0 + 9.0)\ \text{mL} = 10.0\ \text{mL} \\ c_\text{f} &= ?\end{aligned}$$

$$\begin{aligned}c_\text{i}V_\text{i} &= c_\text{f}V_\text{f} \\ c_\text{f} &= \frac{c_\text{i}V_\text{i}}{V_\text{f}} \\ &= \frac{(0.007\,567\,567\,6\ \text{mol/L})(1.0\ \cancel{\text{mL}})}{(10.0\ \cancel{\text{mL}})} \\ &= 7.567\,567\,568 \times 10^{-4}\ \text{mol/L}\end{aligned}$$

Calculate the pOH.

$$\begin{aligned}\text{pOH} &= -\log\left[\text{OH}^-(\text{aq})\right] \\ &= -\log\left(7.567\,567\,568 \times 10^{-4}\ \text{mol/L}\right) \\ &= 3.12 \quad \leftarrow \text{ 2 significant digits}\end{aligned}$$

The resulting pOH is 3.12.

c. The pOH of this solution will be 4.12. Every time the $[\text{OH}^-(\text{aq})]$ decreases by a factor of 10, the pOH increases by one full unit.

Try This Answers

Lesson 5

TR 1. A sample data table is given.

Drop	Contents	Colour
1	red cabbage juice and lemon juice or vinegar	pink
2	red cabbage juice and water	purple
3	red cabbage juice and baking soda	blue-green

TR 2. The colour changes observed in drops 1 and 3 are distinctly different colours. A dilute pink colour does not appear blue-green.

TR 3. Red cabbage juice could be used as a replacement for litmus because there are distinctly different colours for an acidic solution and for a basic solution. It allows for a clear indication of the acidity or basicity of the solutions.

Self-Check Answers

SC 1. Section 6.3 Questions 1(a), 1(b), 1(d), and 2 on page 247

1. a. pink
   b. yellow
   d. orange (mixture of molecules that are red and yellow)
2. a. less than 4.8
   b. greater than 12.0
   c. greater than 5.4
   d. between 6.0 and 7.6

SC 2. The colour of the orange IV is red for pH values that are less than or equal to 1.4.

SC 3. Determine the pH of the solution.

$$\begin{aligned} \text{pH} &= -\log\left[H_3O^+(aq)\right] \\ &= -\log\left(7.2\times10^{-4}\ \text{mol/L}\right) \\ &= 3.14 \end{aligned}$$

a. Thymol blue is yellow for pH values that are greater than or equal to 2.8.
b. Methyl orange is red for pH values that are less than or equal to 3.2.

SC 4.

a. Determine the pH of the solution.

$$\begin{aligned} \text{pH} &= -\log\left[\text{H}_3\text{O}^+(\text{aq})\right] \\ &= -\log\left(1.0\times10^{-1}\ \text{mol/L}\right) \\ &= 1.00 \end{aligned}$$

At this pH, thymol blue is red.

b. Determine the pH of the solution.

$$\begin{aligned} \text{pH} &= -\log\left[\text{H}_3\text{O}^+(\text{aq})\right] \\ &= -\log\left(1.0\times10^{-6}\ \text{mol/L}\right) \\ &= 6.00 \end{aligned}$$

SC 5. According to the data, the three indicators show the following:

- **phenolphthalein:** colourless = below pH 8.2
- **cresol red:** yellow = below pH 7.0
- **chlorophenol red:** red = above pH 6.8

Therefore, the estimated pH of the solution is between 6.8 and 7.0.

© 2008